AN ABSTRACT OF THE THESIS OF

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Title: Simulation of Environmental, Biological, and Fisheries Effects on Yields of English sole (Parophyrs vetulus) off Oregon and Washington

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Abstract approved: ______________________

Albert V. Tyler

English sole is a major contributor to Oregon and Washington groundfish resources. In accordance with the continued trend of increasing fishing effort, in 1975 Oregon State University Sea Grant funded an extensive groundfish research program: the Pleuronectid Project. The purpose was to provide information to assist resource management agencies. This thesis is a computer simulation of potential yields of English sole in the International North Pacific Fisheries Commission (INPFC), Columbia and Vancouver Areas, and is one of the steps in the project.

To initiate this study, non-linear equations were fit to data on trawl selectivity, catch utilization, seasonal growth, and length at maturity. The computer simulation model, ENGLSH, was used to integrate these parameter estimates and other valid information. The model was used to examine effects on yields of varying growth and recruitment rates, ogive and knife-edge instantaneous fishing (F) and discard mortality rates, and migration, and estimate maximum sustainable yield (MSY).

Model validation suggests that Oregon Department of Fish and Wildlife groundfish surveys overestimate recruitment biomass. The simulation model also indicates that E. A. Best's (1961) 5.5-inch mesh ogive approximates annual fleet selectivity in Pacific Marine Fisheries Commission Area 3A during years 1969 to 1979. A small amount of ogive discard mortality, less than ten percent of the applied F, reduces optimum F by at least 0.5.

Natural variability in growth rate, with half the coefficent of variation of natural variability of recruitment rate, produced double the variation in yield. Most of this difference may be explained by the synchronous effect of varying growth over all cohorts in the event year, versus the recruitment effect being dampened by all other cohorts in the population in that year. On the other hand, when maximum and minimum observed deviations in growth or recruitment were made to persist over years, recruitment produced over a 1000 metric tonnes (t) deviation from mean yield while maximum and minimum growth produced an approximate 75 t deviation. This high yield is consistent with the yields observed in commercial catches off Oregon and Washington from the 1961 year class.

MSY is currently estimated at 1850 t and 2500 t for mean cohort analysis and groundfish survey recruitment respectively. Considering (a) that the model indicates that survey recruitment estimates are too high, and (b) that MSY estimates excluded discard mortality for ages 1-3, 1850 t should be considered the upper limit of potential yield for the INPFC Columbia-Vancouver Areas.

Simulation of Environmental, Biological, and Fisheries Effects on Yields of English sole (Parophyrus vetulus) off Oregon and Washington

by

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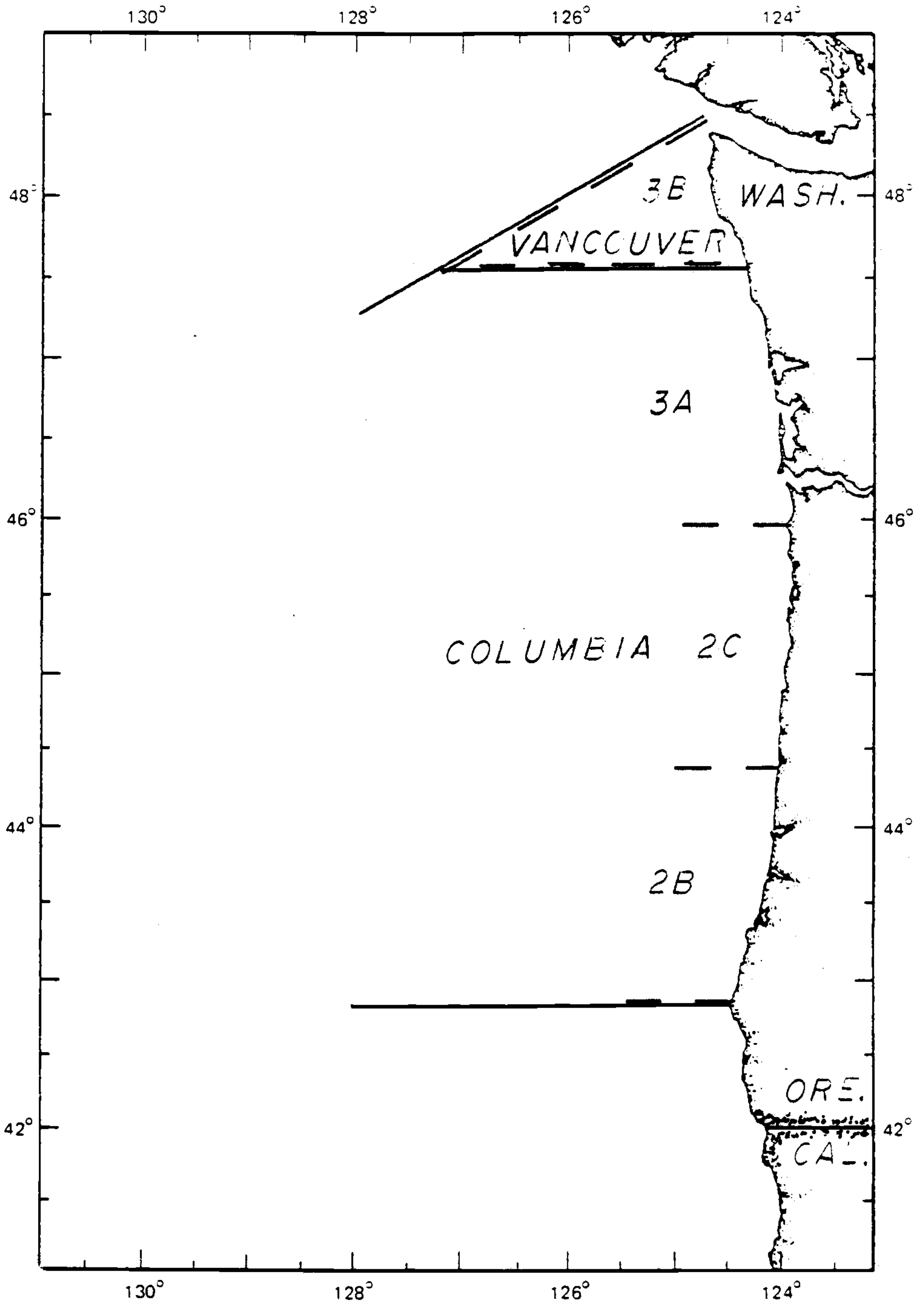
INTRODUCTION

This study uses a computer simulation to examine potential productivity of English sole off Oregon and Washington, Pacific Fisheries Commission Statistical Areas (PMFC) 2B, 2C, 3A and 3B, or International North Pacific Fisheries Commission (INPFC) Columbia and Vancouver Statistical areas (Figure 1). The simulation measures the effects on yield of environmental variations in growth and recruitment, age-specific fishing and discard mortalities and migration within the Columbia-Vancouver area. It also estimates maximum sustainable yield (MSY).

William Lenarz (1978a, 1978b) and Nelson Ehrhardt (1973) have previously modeled portions of the Columbia-Vancouver area. Ehrhardt used a Beverton and Holt yield-per-recruit (Y/R) model of female English sole in PMFC 3B. He concluded that this area was being overexploited during the studied years 1968 to 1970. Lenarz (1978a) examined the female English sole population in PMFC 3A using a Ricker Equilibrium Y/R model. He concluded that this stock was being exploited below MSY based upon parameter estimates from a 1951 to 1970 data base. Lenarz (1978b) also constructed a production model of the same area which also estimated that the fishery was operating below MSY and placed MSY at 862 metric tonnes (t).

Figure 1. The location of the Columbia and Vancouver, International North Pacific Fisheries and 3B, 3A, 2C, and 2B, Pacific Fisheries Commission Statistical Areas.



Oregon State University (OSU) Sea Grant-funded researchers have since completed studies of the growth (Kreuz 1978; Kreuz et al. 1982) and recruitment (Hayman 1978; Hayman and Tyler 1980; Kruse and Tyler 1983; Kruse 1984) of English sole off Oregon. This information coupled with mesh selectivity (Best 1961), catch utilization studies (TenEyck and Demory 1975), and the Oregon Department of Fish and Wildlife (ODF&W) groundfish trawl survey data make pos the construction of a new, less constrained fisheries model.

The growth studies of Kreuz and associates (1978, 1982) provide environmentally driven, annually varying, and mean growth models. These works also help eliminate geographic constraints of previous models by providing one growth expression for all four PMFC Areas. Kreuz's (1978) seasonal growth information provides an estimate of average annual length-at-age to accommodate the different timing of fisheries efforts in the Columbia-Vancouver Areas.

The recruitment studies of Hayman, Tyler, and Kruse (1978,1980 and 1984) provide environmentally driven and mean recruitment estimates as well as estimates of instantaneous fishing mortality (F) and instantaneous natural mortality (M) for PMFC Area 3A. One objective of this research was to examine varying rates of growth and recruitment and what would happen without the extremely good years that occur about once a decade. Another objective was to determine whether recruitment or growth has the greater effect on yield.

ODF&W groundfish survey results (Barss et al. 1977; Demory et al. 1976; Demory and Robinson 1972; Demory et al. 1978; Barss 1976; Demory and Robinson 1973) provide recruitment, mortality and length-weight parameter estimates for all four PMFC Areas. Their recruitment data provide information to expand the geographic contraints of the recruitment model to all four PMFC Areas, thus allowing construction of a simulation model of the Vancouver-Columbia Management unit.

The gear savings studies of E. A. Best (1961) provide length-specific fishing mortality information, necessary to measure the full effects of annually varying growth on yield from this management area.

The catch utilization study of TenEyck and Demory (1975) adds length-specific catch utilization to fishing and discard mortalities. These length-specific parameters also increase model sensitivity to growth variations and the resulting effects on yields.

The inclusion of all these biological and fisheries parameters in this simulation removed several constraints which prevented previous models from examining various population parameters and fishery management strategies. Since females constituted over 90 percent of the commercial landings of English sole from 1959 to 1979, the review of general biology and the remainder of this report will be concerned with female English sole unless otherwise specified.

BACKGROUND MATERIAL

Distribution

English sole have been found from Sebastian Vizcaino Bay, Baja California to Unimak Island in Western Alaska (Forrester 1969). The species is distributed all along the Oregon and Washington coasts and has been found in depths ranging from the surf line to 550 meters (Barss 1976). Commercial fishing and research trawl surveys indicate that English sole shift their depth distribution from shallower water (18-73 m) in the spring to deeper water (37-91 m) in the winter months (Alverson 1960, Barss 1976). It is generally accepted that smaller English sole, those less than 14 cm total length, inhabit the inshore beaches, bays and estuaries (Pearcy and Myers 1974; Laroche and Richardson 1977; Westrheim 1955; Laroche and Holton 1976), and as they grow older gradually move into deeper offshore waters (Demory 1971; Barss 1976). The occurrence (2 percent of the total catch) of age 1+ fish in the September ODF&W groundfish surveys confirms that they are recruited to the fishing grounds during their second year of life (age 1+).

Life History

The size and age at 50 percent maturity for female English sole off Astoria is 29.5 cm total length or 4.2 years with 100 percent maturity attained by age five (Harry 1959). Peak spawning for sole off Oregon lasts one to three months within the period of September through April (Kruse and Tyler 1983). It is generally concluded that these fish spawn in water that is deeper (37 to 91 m) than that which is inhabited during summer months (Demory 1971; Barss 1976; Hewitt 1980).

English sole experience seasonal and annual variations in growth (length at age), with the majority of seasonal growth occuring from April through June (Kreuz 1978). Annual variations in growth of +13 to -17 percent have been observed (Kreuz et al. 1982) and related to bottom temperature (Kreuz 1978). Studies also suggest that growth rate variations are synchronous among ages two through eight (Kreuz et al. 1982) and are similar along the entire Oregon and southern Washington coasts (Kreuz 1978).

Long-distance migrations to Vancouver, Canada and Eureka, California of fish tagged off Oregon and Washington occur (Harry 1956; Pacific Marine Fisheries Commission 1960; Barss 1976), but are sporadic (Ehrhardt 1973). It is felt that the Juan de Fuca Canyon and Blanco Reef present physical obstruction to migration (R. L. Demory, personal communication, 1982) and prevent consideration of the entire INPFC Columbia-Vancouver statistical areas as a management unit or stock as defined by Gulland (1969). The general migratory pattern within this management area is a northern movement in early winter and spring, occupation of the northern area during the summer and a return south in late fall and early winter (Golden et al. 1979).

History of the Fishery

The Oregon-Washington trawl fishery became a viable industry due to thriving food markets created by the World War II armed forces of the United States. Food fish markets declined following the war, and in 1953 Oregon and Washington trawl landings reached a post-war low. The fish market began a slow recovery in 1956, initiated by increasing demands for non-human use, and by 1960 the trawl fishery had recovered (Harry and Morgan 1963). The market demands continued to dominate commercial landings of English sole for the next two decades (R. L. Demory, personal communication, 1983), with annual landings averaging 1500 t from 1960-79 (Table 1). It is recognized that English sole can sometimes produce an enormous year class that will dominate the fishery for many years. The 1961 year class is an example of such an event and accounted for high landings in 1966. Commercial catch composition records for PMFC Area 3A (Table 2) illustrate that the effects of that year class were visible until 1975 when twice the previous percentage of age-14 fish were observed.

Time series of the age compositions from Area 3A for ages four and seven (Figure 2) illustrate a shift to larger fish in 1968, the time the 1961 year class entered the fishery. This trend persisted beyond the demise of the 1961 year class from the fishery, suggesting the entry of another strong year class and a change in fleet selectivity characteristics. At present, processors impose stricter size limits (12-12.5 inches minimum size) than the ODF&W pending regulations (R. L. Demory, personal communication, 1982).

Analysis of the seasonality of commercial catches for PMFC Areas 3B, 3A, 2C, and 2B illustrates that fishing effort in Areas 2C and 2B (Figure 3) is shifting toward the end of the year while Areas 3B and 3A illustrate no trend. A time series of monthly landings for these areas (Figure 4) indicates the efforts in Areas 3A and 3B are similar and low at the beginning and end of the year with the majority of landings occurring in April through October, while Areas 2B and 2C show the opposite effect with peak fishing occurring in October through March.

Table 1. Landed catches (t), effort (t/hr), and nominal (nt/hr)* for English sole caught in Pacific Marine Fisheries Commission Areas 3B, 3A, 2C, and 2B. Nominal effort was computed from landings where English sole comprises 29 percent or more of catch.

Pacific Marine Fisheries Commission Areas

	3B		3A		2C		2B		TOTAL
YEAR	CATCH	CPUE*	CATCH	CPUE	CATCH	CPUE	CATCH	CPUE	CATCH
1959			618	.165	19	.047	49	.099	
1960	1182	.120	761	.167	172	.081	106	.129	2221
1961	909	.100	582	.124	50	.073	85	.097	1626
1962	704	.120	660	.126	109	.082	225	.175	1698
1963	749	.098	575	.117	139	.114	116	.097	1579
1964	737	.094	419	.137	140	.106	56	.060	1352
1965	904	.124	440	.173	180	.079	68	.088	1592
1966	745	.085	1100	.228	184	.096	206	.209	2235
1967	623	.106	572	.161	141	.090	155	.123	1491
1968	822	.109	456	.127	133	.094	127	.109	1583
1969	549	.070	439	.114	112	.090	71	.152	1171
1970	135	.040	362	.112	116	.102	201	.119	814
1971	109	.030	313	.097	147	.102	239	.125	808
1972	236	.050	376	.159	189	.140	346	.105	1147
1973	379	.070	363	.118	253	.112	321	.088	1316
1974	366	.040	296	.144	140	.087	285	.147	1087
1975	486	.050	372	.110	305	.083	293	.108	1456
1976	684	.060	921	.176	299	.134	498	.128	2402
1977	266	.040	371	.122	318	.102	342	.109	1297
1978	480	.040	718	.169	178	.074	152	.068	1528
1979	424	.050	697	.106	177	.067	224	.081	1522

Table 2. Percentage age composition of landed female English sole for Pacific Marine Fisheries Commission area 3A, years 1959 to 1979.

Year	AGE 2	3	4	5	6	7	8	9	10	11	12	13	13+
1959	0.3	5.6	19.9	33.6	24.7	7.6	3.5	2.1	1.8	0.8	0.1	0.1	
1960	1.1	9.3	24.9	34.0	20.6	5.1	2.1	1.3	1.1	0.5	0.1	0.1	
1961	0.1	5.3	20.7	35.4	24.3	6.6	3.0	1.9	1.6	1.0	0.1	0.1	
1962			20.9	29.7	16.8	8.8	5.2	5.2	0.8				
1963	0.2	5.3	20.6	31.3	23.3	8.5	3.0	3.4	3.4	0.9			
1964	0.6	7.3	21.5	33.4	23.4	6.8	3.0	1.7	1.5	0.7	0.1		
1965	0.7	9.5	26.0	32.9	20.2	5.0	2.2	1.4	1.2	0.7	0.1		
1966	0.4	4.0	26.9	43.6	12.2	7.5	1.9	1.7	1.3	0.7			0.1
1967	0.3	5.1	15.6	29.1	34.6	7.5	3.8	1.7	1.1	0.9	0.2	0.1	0.1
1968	0.2	5.1	15.4	17.8	21.2	27.0	7.0	3.3	1.4	0.9	0.5	0.1	0.1
1969	0.1	8.0	18.5	25.1	13.2	16.4	11.9	3.5	2.0	0.6	0.5	0.3	0.1
1970		4.6	17.2	23.5	20.4	12.6	8.9	7.8	3.0	1.3	0.5	0.3	0.1
1971		3.5	14.5	34.6	20.3	12.6	4.6	3.7	3.9	1.4		0.6	0.4
1972		1.2	10.8	21.7	22.3	13.7	11.2	5.4	3.7	4.9	1.3	1.1	0.2
1973		6.9	18.5	29.1	16.7	15.3	6.9	3.7	1.2	1.1	0.3	0.2	
1974		2.8	18.1	21.6	24.2	11.3	10.3	8.2	3.1	1.9	0.5	0.7	0.3
1975		1.8	9.5	24.6	22.6	15.8	8.6	9.2	3.7	1.5	1.3	0.4	0.9
1976		2.8	17.0	29.0	18.0	15.0	10.0	7.5	3.2	1.8	1.2	0.4	
1977	0.2	5.0	17.0	19.0	18.0	16.0	10.0	5.0	3.0	3.0	2.0	0.3	1.1
1978		1.4	6.9	23.1	20.9	17.7	17.0	7.7	3.1	0.8	0.8	0.3	0.3
1979	0.1	0.8	9.9	22.4	25.4	18.6	9.6	6.4	3.9	1.9	0.5	0.2	0.2

Figure 2. Percentage of age-four and -seven female English sole in Commercial landings from Pacific Marine Fisheries Commission Area 3A, years 1959-79.

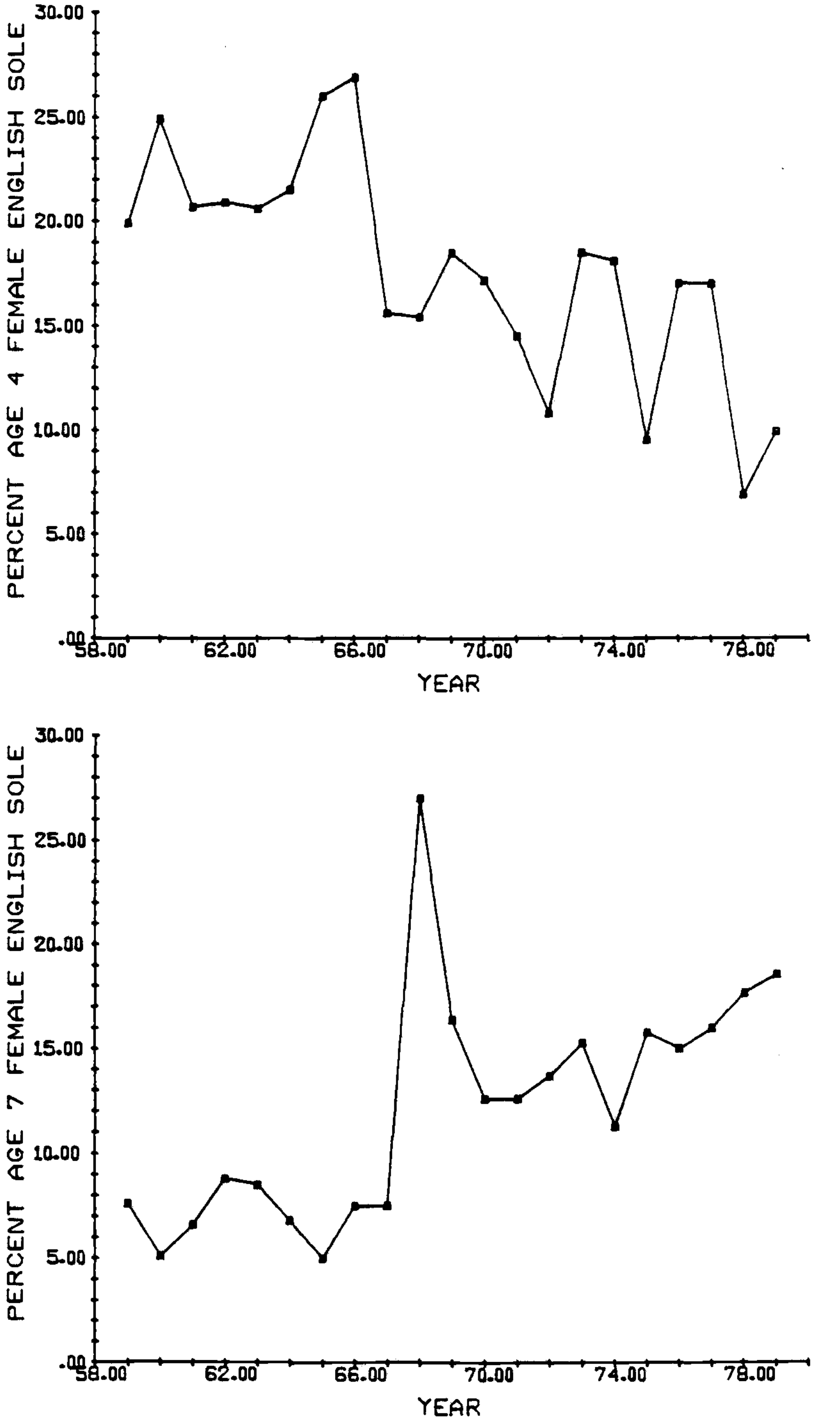


Figure 3. Number of days till half annual commercial catch of English sole landed for Pacific Marine Fisheries Commission Areas 3B, 3A, 2C, and 2B, years 1971-79.

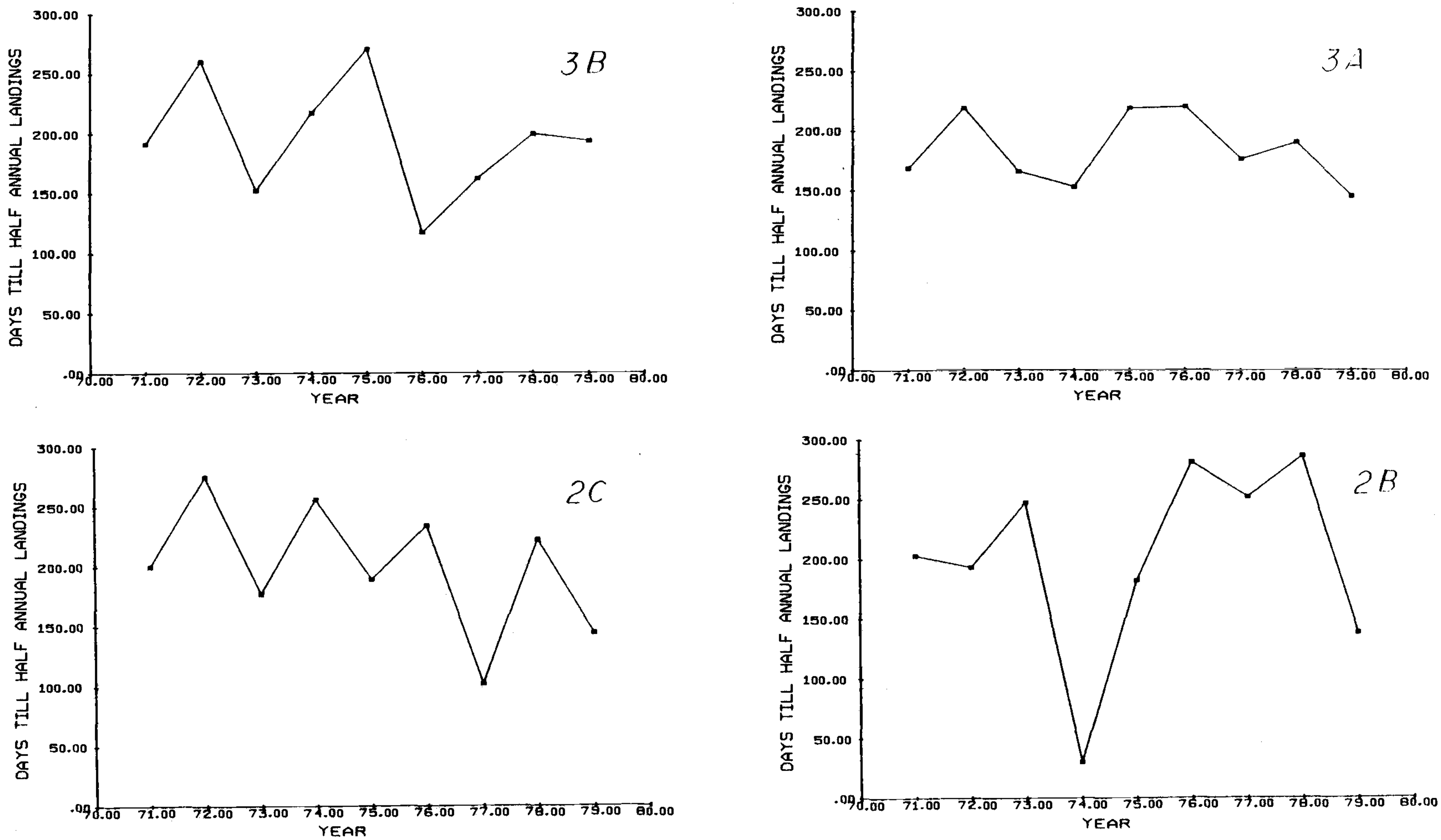
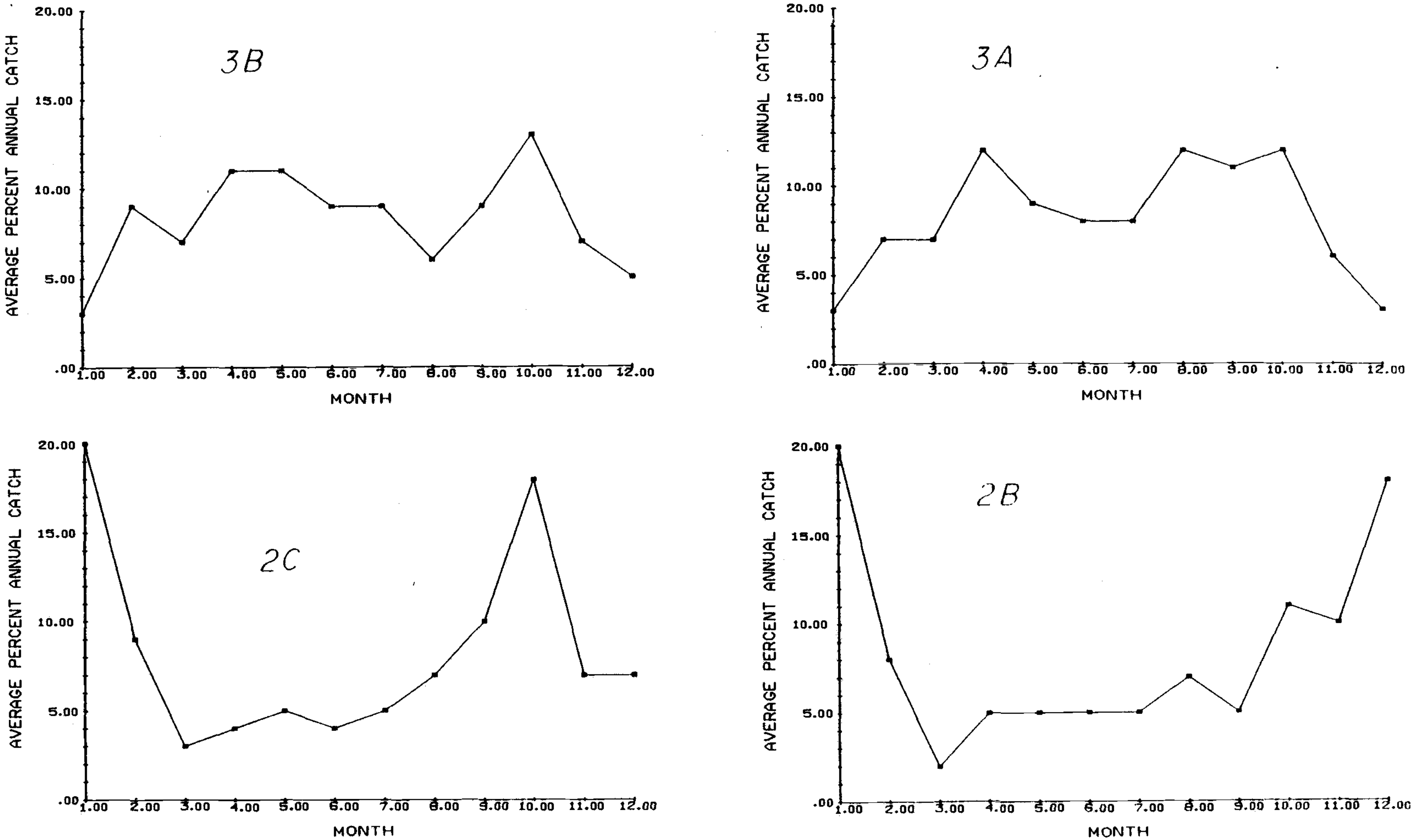


Figure 4. Average percent of annual commercial landings by month of English sole for Pacific Marine Fisheries Commission Areas 3B, 3A, 2C, and 2B, years 1971-79.



A record catch of 2400 t was landed in Oregon and Washington in 1976 (Figure 2). Demory attributes this to a relatively good market and large fleet size.

The fleet grew in numbers, size and horsepower during the 1970's (Tables 3 and 4). The type of vessel also changed in the 1970's from the converted wooden vessels characteristic of the 1950's and 1960's to the new steel vessel built specifically for trawling. This change was accompanied by refinements in gear and advances in electronic fishing equipment (W. H. Barss, personal communication, 1982).

Characteristic of most trawl fisheries is the practice of discarding of unmarketable fish at sea. Herrman and Harry (1963) noted that in 1950 half the catch by trawlers off Oregon was discarded at sea. TenEyck and Demory (1975) examined catch aboard Oregon trawlers off Newport, Oregon and estimated that age at 50 percent utilization for female English sole was 3.6 years. They reported that 4.5-inch mesh size was most frequently used by the commercial vessels they studied in 1974.

In June 1978 trawl grounds off British Columbia were closed to U. S. fishermen, forcing many Washington fishermen into waters off their state. The results of this and the increasing Oregon fleet has created a trawl fleet off Oregon and Washington capable of overexploiting the existing resources and causing concern to fishery management administrators.

Previous Yield Per Recruit Estimates

The first published estimates of yield-per-recruit for English sole off Oregon and Washington were conducted by Ehrhardt (1973) on the

Table 3. Number of trawl vessels by length catagories for the Oregon groundfish fleet.

		Length in feet						
Time period	Number of boats	30-39	40-49	50-59	60-69	70-79	80-89	>90
Before 1944*	24	0	2	11	10	1	0	0
1944 - 1956*	30	0	3	8	10	7	1	1
1970+	36	1	4	10	14	7	0	0
1978@	81	5	11	22	21	19	1	2
1979@	109	3	11	28	26	33	6	2
1982^	152							

* From Harry (1956)

+ Data incomplete, no length data available for 28 vessels

@ Boats making more than five trips

^ 152 vessels make one or more landings in 182

Table 4. Number of trawl vessels by horsepower catagories for the Oregon groundfish fleet.

Time period	Number of boats	1- -99	100- 199	200- 299	300- 399	400- 499	500- 599	600- 699	>700
1943-1954	54	6	40	6	1	1	0	0	0
1978@	81	3	24	17	28	3	4	1	1
1979@	110	0	27	23	42	10	5	1	2
198-*	152								

@ Boats making more than five trips.

* 152 vessels made one or more landings in 1982.

female English sole in PMFC Area 3B. He used a Beverton and Holt method and applied his estimates of the Von Bertalanffy growth, F, M and set age at recruitment to the fishing ground or age at entry to the area where fishing is in progress (tp=3.6), and recruitment to the fishery or age at becoming vulnerable to the fishing gear (tp'=4.0). His growth estimates came from interopercula agings of 1960 to 1961 commercial catch samples, and estimates of F and M from 1967 to 1970 Washington Department of Fisheries tagging data. The resultant yield-per-recruit curves (Figure 6) suggested that F should be reduced from 0.90 to 0.75 or tp' increased from 4.0 to 5.5 years.

The other yield-per-recruit estimate of English sole off Oregon and Washington was done by Lenarz (1978a) for female fish in PMFC Area 3A. He used the Ricker method which allowed him to incorporate his estimates of age-specific fishing mortality, along with growth and mortality estimates from Demory et al. (1976) and catch utilization rates (TenEyck and Demory 1975). He estimated age-specific fishing mortality by using the ratio of cohort estimates of F at age for the years 1957 to 1965. He set tp at 3.0 years and using Leslie Matrix, his selectivity operated over ages three to five. Results from his analysis (Figure 7) suggest that the fishery was operating below MSY at that time and his selectivity data suggested that an increase in mesh size would produce a small increase in yield.

Figure 5. Yield per recruit and fishing mortality rate for three values of M; tp = 4; tp' = 3.6; from Ehrhardt 1973.

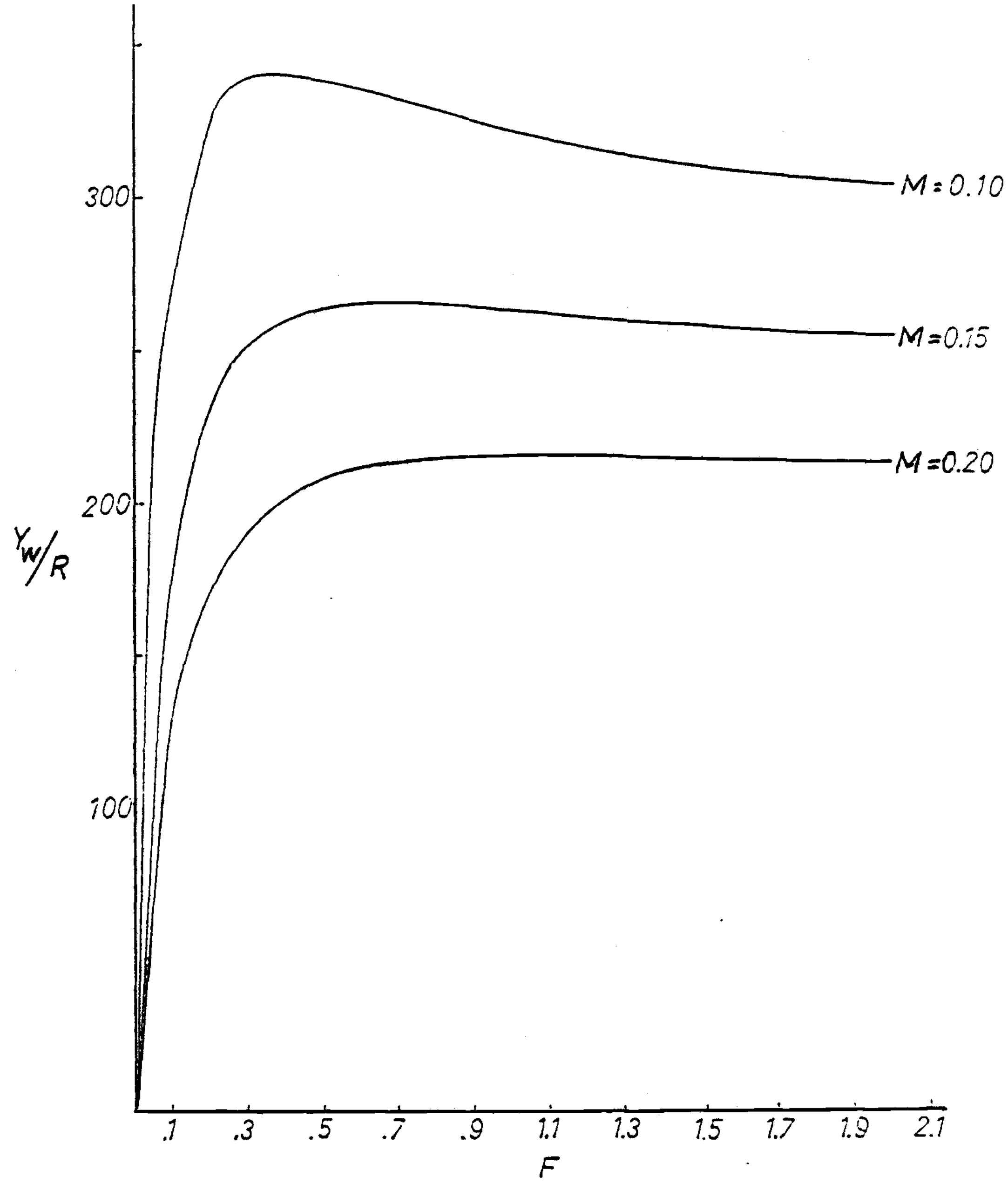
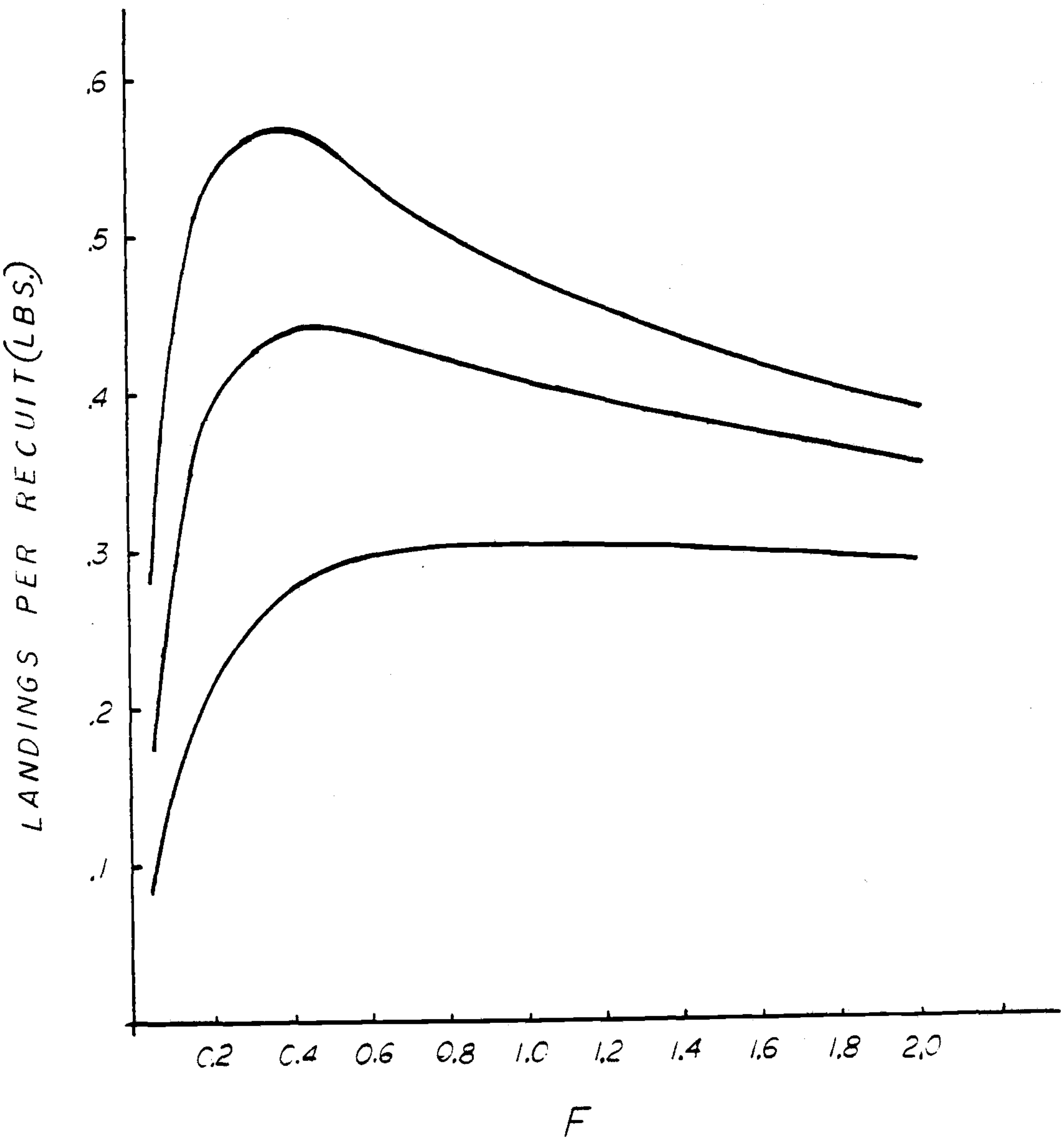


Figure 6. Yield per recruit and fishing mortality rate for three values of M; tp = 3; tp' = selection matrix,; from Lenarz 1978a.



MORTALITY RATES

The mortality rates which are available for English sole off Oregon and Washington are presented in Table 5. Ehrhardt selected his mortality estimates by comparing variability among six sets of data using four different recapture models from Washington Department of Fisheries tagging studies conducted in 1966 to 1969. Hayman estimated instantaneous total mortality (Z) using catch curve analysis of commercial catch data (1971 to 1974) and ODF&W estimate of instantaneous fishing mortality (F). These analyses estimated average F for these years at 0.293 for PMFC 3A. ODF&W estimates of Z were derived using the Robson and Chapman (1961) method. They computed F using their estimates of exploition rate (u), Z and annual total mortality (a) (Barss et al. 1977).

The estimates of Z by Ehrhardt for Area 3B are noticably different from those of Barss (Table 5). The fishing effort that was higher in Area 3B during Ehrhardt's study period 1967 to 1970 than during the groundfish surveys of 1975 and 1976 (Table 1) explains some of this difference. Commercial catch records illustrate that effort was half again higher in Area 3B during 1967 to 1970 than in 1975 and 1976. This suggests that the fishing mortality component of Z would account for half of the difference and the remainder (approximately 0.1) could be due to observational bias in the studies.

Comparing area estimates of Z from ODF&W suggests that there was little difference between PMFC Areas 3A, 2B, and 2C, while 3B was about half again higher. This difference suggests either that F was higher, or that southward spawning migration had begun by the September survey period and influenced the age compositions in Area 3B. These two

Table 5. Estimates of instantaneous fishing (F), natural (M), and total (Z) mortality rates by Pacific Marine Fisheries Commission Area, year, and source.

PMFC	MORTALITY ESTIMATES				
AREA	Z	M	F	YEAR	SOURCE
3B	1.04	0.14	0.90	1967-1970	Ehrhardt 1973
	0.60	0.40	0.21	1975&1976	Barss et al. 1977
3A	.494	.201	.293	1963-1972	Hayman et al. 1980
	.43	.24	.19	1971,73,75&76	Demory et al. 1976
2C	.48	.41	.07	1971&1973	Demory et al. 1976
2B	.48	.21	.27	1972&1974	Demory et al. 1976

possiblities were examined during the model validation.

Estimates of Age Specific Fishing Mortality

Trawl fisheries are characterized by at-sea sorting and discarding of unwanted species. This presents problems when modeling at-sea and landed catches and accounting for deaths in the population due to discards. For this study, it was decided that these mortalities would be modeled with length-specific rather than age-specific parameters. To incorporate length-specific fishing mortality into the model and measure the effects of varying growth rates on yield, it was necessary to include length-specific fleet selectivity, and catch utilization and discard rates (Gulland 1969).

Fleet Selectivity

Fleet selectivity, also referred to as recruitment, is that portion of the population entering the exploited phase or becoming vulnerable to the fishing gear. This "recruitment" denoted as tp' by Beverton and Holt (1957) will be refered to as "fleet selectivity" in this study. The gear savings studies of E. A. Best (1961) provide the only available data on trawl selectivity for English sole. His 4.5-, 4.8-, 4.9-, 5.5- and 5.6-inch mesh data were used to develop the mesh selectivity models. These data were standardized using a method described on pages 222-233 in Beverton and Holt (1957). Best's study was conducted using otter trawls constructed of cotton rather than synthetic materials. It was assumed that the ogives fitted to these data were similar in shape to synthetic mesh ogives and would give a realistic representation of the fleet selectivity. Another study was carried out using length and girth (Westrheim and Foucher 1986), and comparison of their 50 percent retention lengths with those of Best's (Table 6) suggest the cotton ogives retain smaller fish than equal mesh length trawls of current synthetic materials.

The model selected to represent fleet selectivity is a two parameter logistic equation,

$$s(L) = 1 - \frac{1}{1 + e^{-(S1-S2)L}} \qquad (1)$$

where s(L) is that portion of total F (Gulland 1969) or F^{∞} (Beverton and Holt 1957) selected from the fish population entering the trawl, S1 and S2 are parameters, and L is the total fish length (cm).

SPSS NONLINEAR regression (Robinson 1977; Nie et al. 1975) was used to estimate parameters for the fleet selectivity model. The regressions were weighted by the number of observations at each length to give more emphasis to those lengths with more observations and the inverse for lengths with few observations. The regressions were allowed to default to iterative termination tolerance limit 1 (maximum iterative relative change in parameters is less than 1.5×10^{-8}), numerical estimation of derivatives, Marquardt curve-fitting algorithm and maximum number of iterations was set at 25.0. Graphical estimations were used for initial parameter values. Equation 1 was altered to accommodate the curve fitting requirement that all initial parameter values be equal in order of magnitude. The proportions selected for various trawl mesh sizes were regressed with fish total lengths. The estimated fleet selectivity curves and parameter estimates are presented in Figure 7.

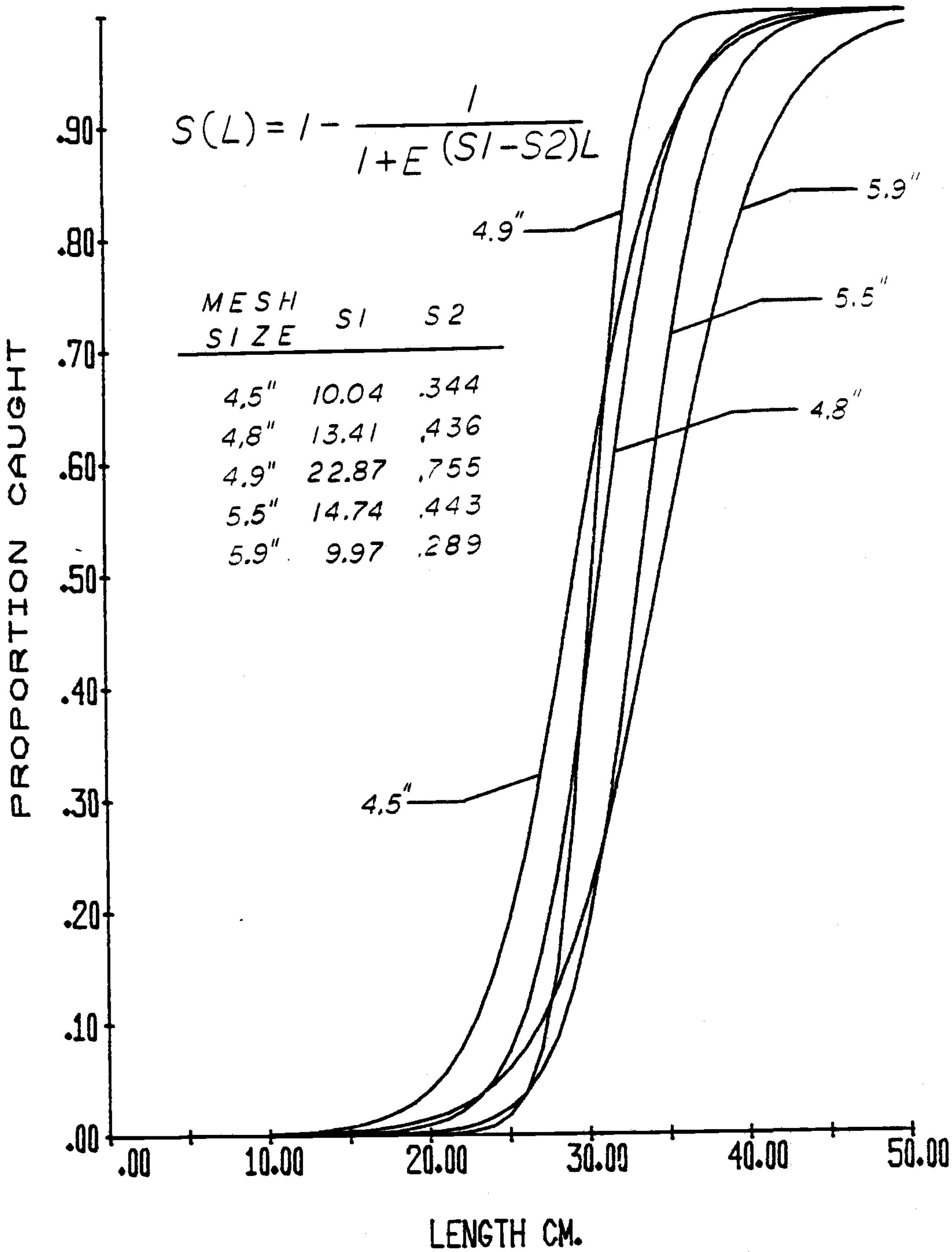
Table 6. Fifty percent selection or retention lengths of Cod-ends used for female English sole from E. A. Best (1961)@ and Westrheim and Foucher (1986)*.

Mesh size (inches)	50% selection@ length	50% retention* length
5.0		34.3
5.5	33.6	38.1
5.6	35.8	
5.9	35.5	
6.0		44.5

@ E. A. Best measured total length.

* Westrheim and Foucher measured fork length.

Figure 7. Adjusted ogives for cotton cod-ends used on female English sole, from E. A. Best, 1961.



Catch Utilization

The catch utilization study of TenEyck and Demory (1975) is the only study available regarding at-sea sorting, characteristic to this fishery. The same logistic model,

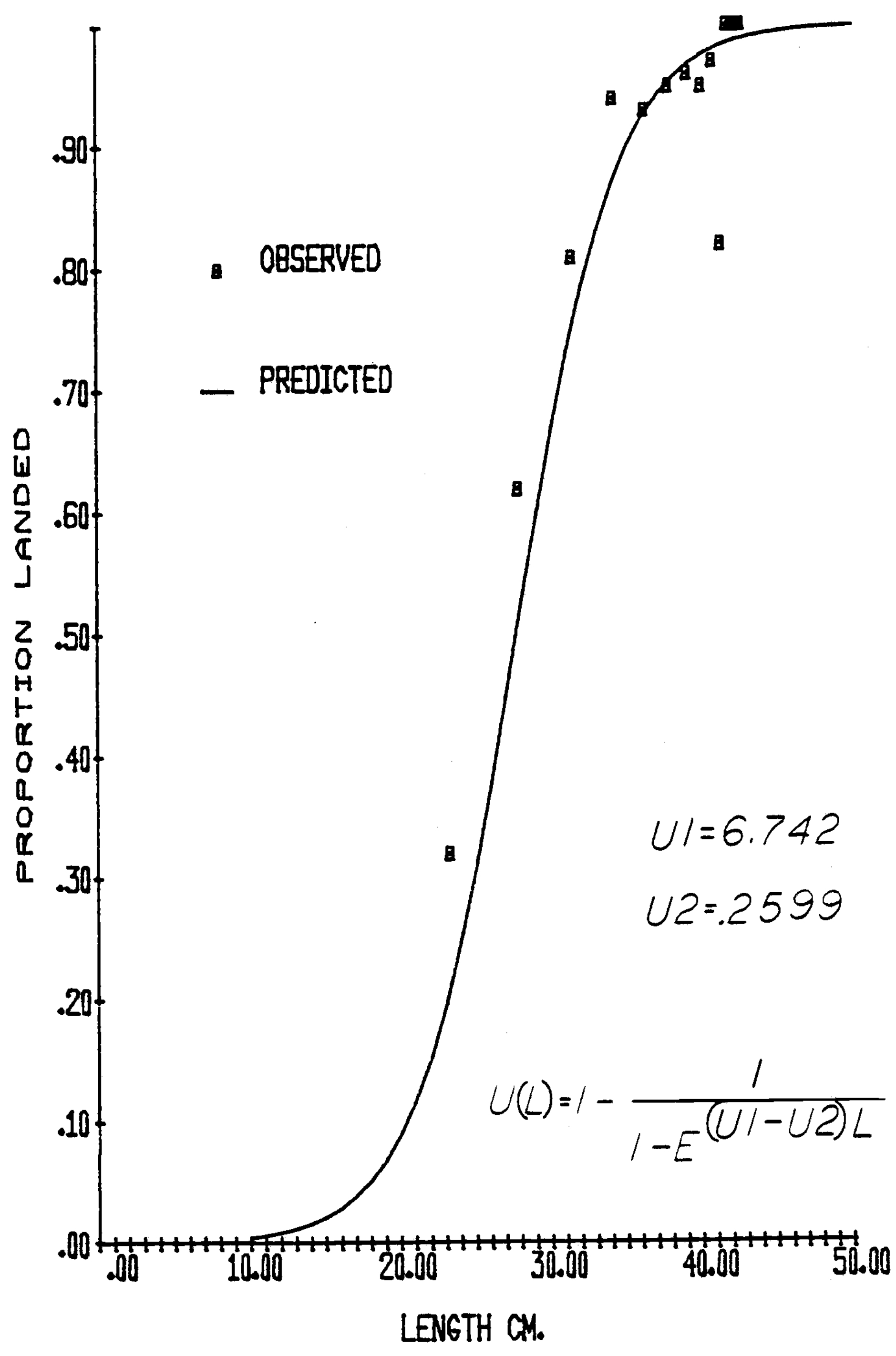
$$u(L) = 1 - \frac{1}{1 + e^{-(U1-U2)L}} \qquad (2)$$

was used to represent proportional length-specific fleet utilization, where u(L) is proportion of at sea catch landed, U1 and U2 are parameters and (L) is as discribed above. The model parameters were estimated using a unweighted version of the SPSS NONLINEAR procedure previously discribed, and the resulting model and parameter estimates along with the observed points are presented in Figure 8. It was assumed that fleet selectivity and catch utilization occurred over the same range of ages (lengths); consequently commercial landings reduced each year class by the factor

$$e^{-suF} \qquad (3)$$

where s is age (length) specific fleet selectivity, u is age (length) specific catch utilization, and F is instantaneous fishing mortality. This represents the portion of those fish entering the net which are retained, and of those, the portion of legal and or marketable size landed.

Figure 8. Catch utilization ogive for female English sole caught by Oregon trawlers, data from TenEyck and Demory 1975.



Discard Mortality

Discard mortality is related to fishing mortality and fleet selectivity and inversely related to utilization. The equation for proportional fleet discards is the reciprocal of catch utilization. Consequently equation 2 becomes

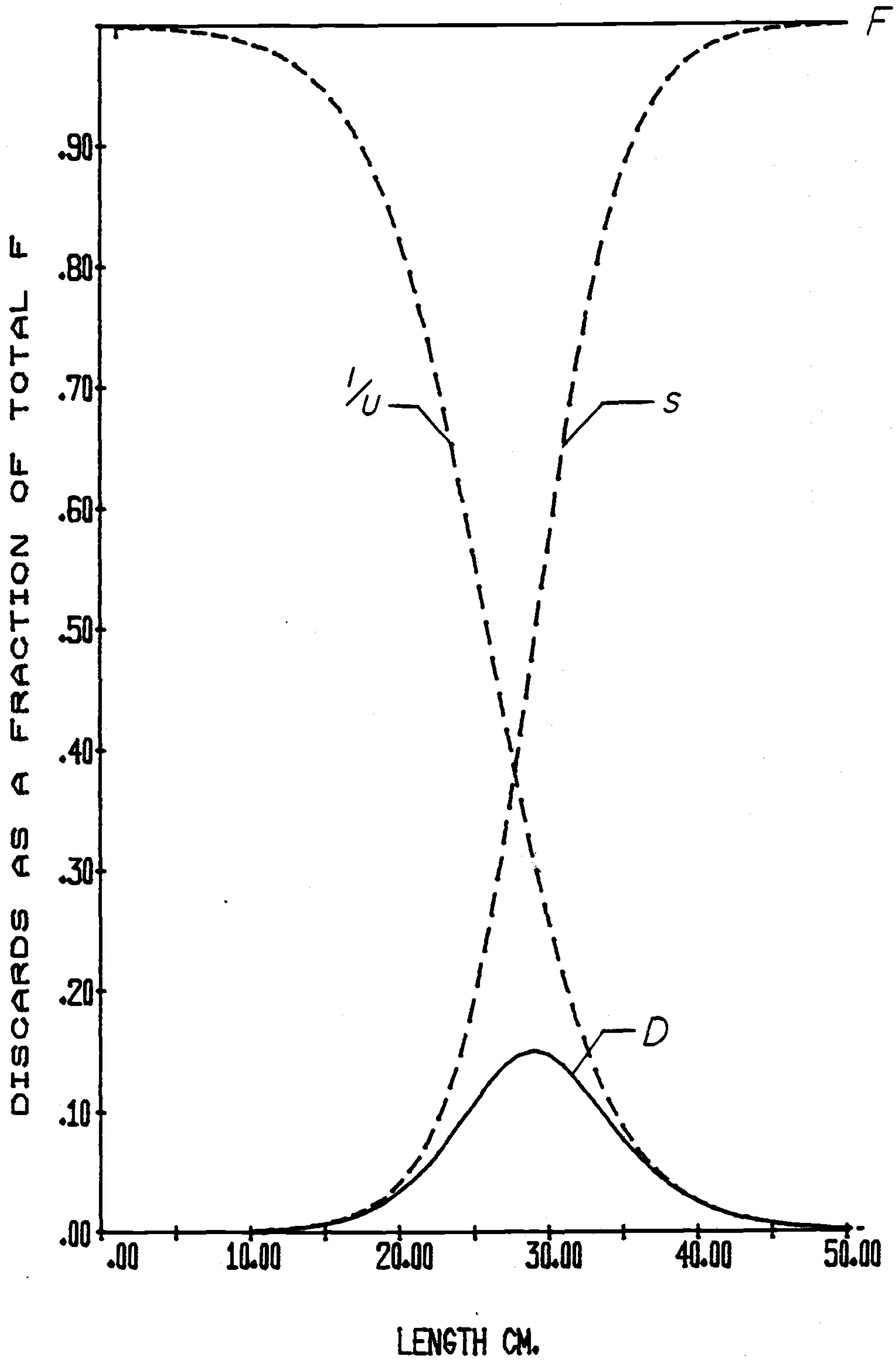
$$d(L) = \frac{1}{1 + e^{-(D1-D2)L}} \qquad (4)$$

where d(L) is the proportion of those fish caught by the net and discarded at sea, D1 and D2 are parameters and (L) is as explained above. The parameter estimates for U1 and U2 from the catch were substituted in the discards model for D1 and D2. Discarding reduced each year class by the factor

$$e^{-asdF} \qquad (5)$$

as a result of capture and discard of undersized or unmarketable fish before they enter the acceptable size range. The term 'a' included in equation 5 is the fraction of discarded fish that die. It was assumed that a=1.0 unless otherwise specified and s is length-specific fleet selectivity, and d is length-specific fleet discarding as before. Discard mortality is illustrated in Figure 9 using 4.5-inch selectivity, equation 4 and assuming a=1.0. This illustrates that discarding mortality, when fleet selectivity is 4.5-inch as observed by TenEyck and Demory (1975), removes significant portions of fish at lengths 24-35 cm or corresponding ages three (3) to five and a half (5.5).

Figure 9. Ogive fleet selectivity (S) (tp' = 4.5" mesh), discards (1/U) = (1/utilization), and instantaneous Discard Mortality (D) as a fraction of total F or F∞, for female English sole off Oregon and Washington.



SEASONAL GROWTH ESTIMATES

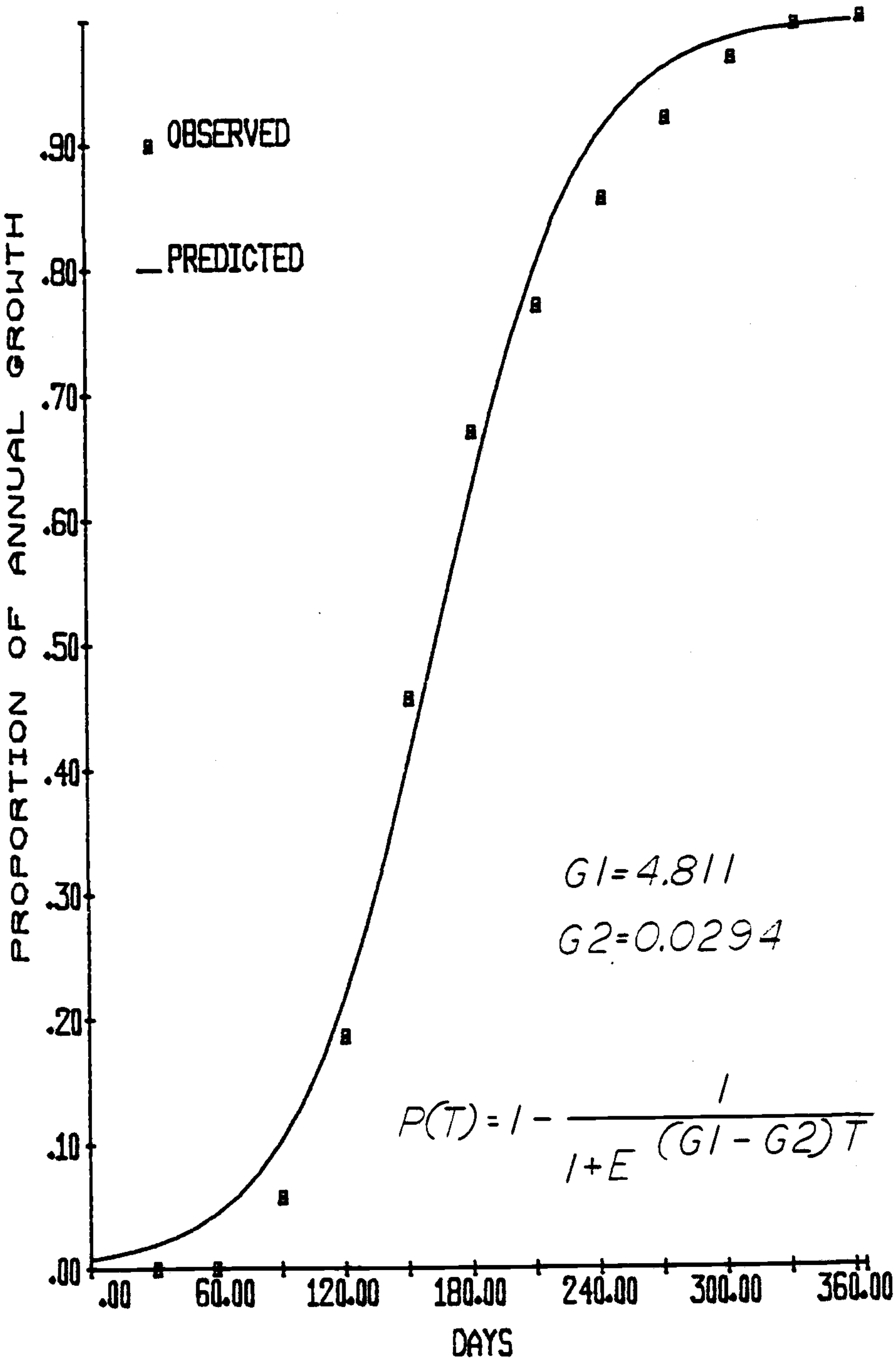
Seasonal variations in growth of English sole in Puget Sound, Washington were discovered by Sayed El Sayed (1959). However, due to incomplete sampling, he was unable to determine the exact time when growth was most active. Keith Kreuz (1978) examined seasonal variation in growth of English sole off Astoria, Oregon using variation in length of interopercular bones, which is linearly related to total length (El Sayed 1959; Smith and Nitsos 1969). Kreuz averaged seasonal variation over age and presented his results as monthly percentage of annual growth (Figure 6 in Kreuz 1978, p. 52). His data were converted to accumulative percentage of annual growth to develop a seasonal growth model. Another logistic equation,

$$P(t) = 1 - \frac{1}{1 + e^{-(G1-G2)t}} \qquad (6)$$

was selected for these data, where P(t) is percent of total annual growth, G1 and G2 are parameters and t is accumulative time in days.

Unweighted SPSS NONLINEAR curve fitting was used to estimate the parameters for the seasonal growth model (equation 6) with NONLINEAR operating as before. The model, parameter estimates, and observed and predicted percentage of annual growth are presented in Figure 10.

Figure 10. Percentage of annual growth versus days of the year for female English sole, data from Kruse (1978).



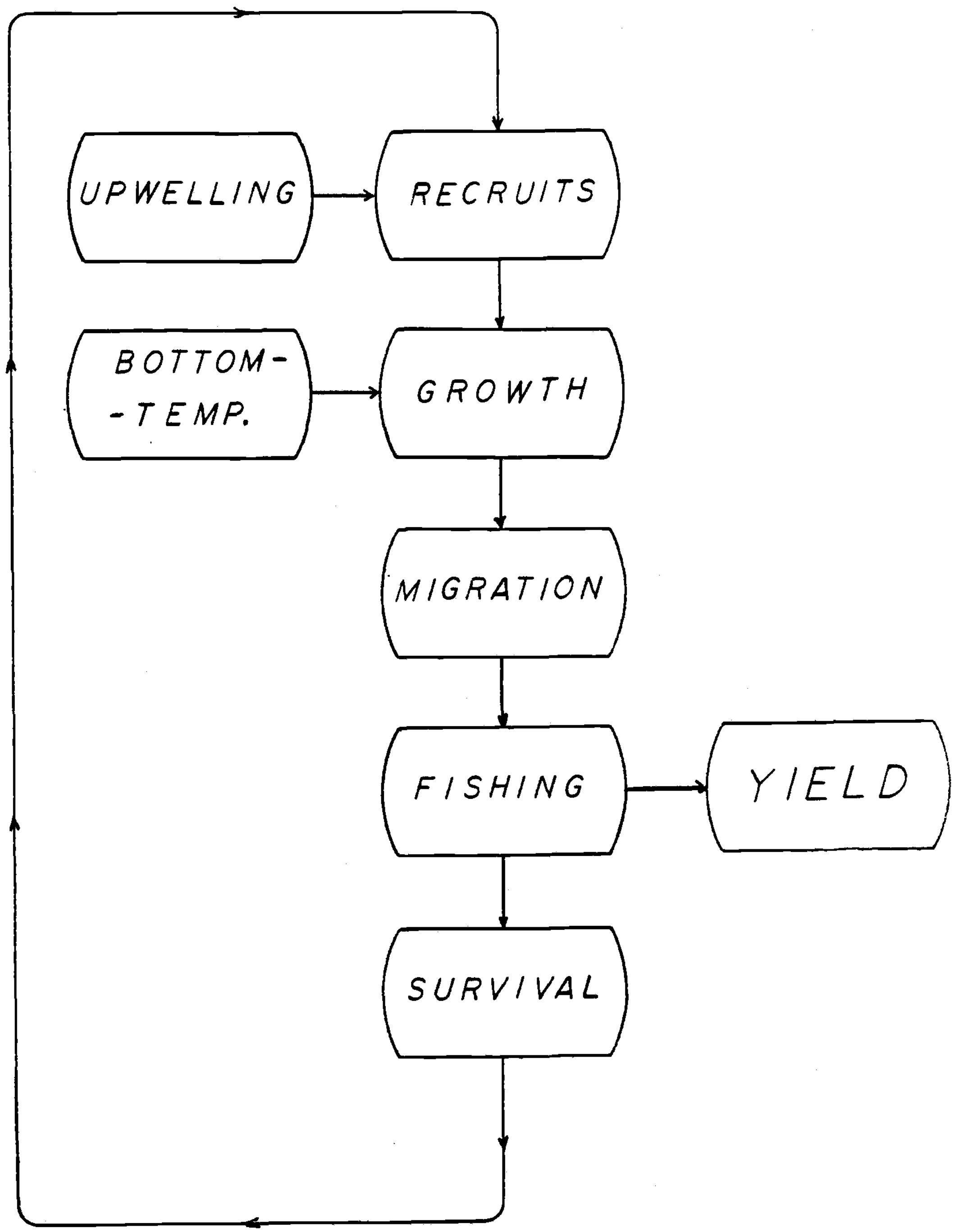
THE SIMULATION MODEL

A simulation model may be constructed of sets of equations representing the observed phenomena in the fish population. This allows the scientist to model the system, examine the sensitivity of the equations to determine their importance, and suggest future research.

The computer simulation model, ENGLSH, was constructed for use in answering the questions proposed in this study. It was written in FORTRAN V and uses the Simulation Control Language SIMCON (Beals 1981; Hilborn 1973) to operate on the Oregon State University (OSU) CDC Cyber 70, model 73. SIMCON was used to facilitate program debugging, eliminate input/output programming, and allow access to and changing of every variable within the program. To reduce operator and computer time, a second Fortran V version of the model, ENGLISH, was written for use in experiments requiring numerous population variable changes

The model logic (Figure 11) began with the assumption that the majority of recruitment (numbers of age-4 fish entering the model) takes place in a brief period at the beginning of the simulated year. This number was either set at an annual average value or varied estimated from a time series of environmental data. Mean length and weight at age was calculated next and was also either set at annual averages or varied related to another time series of environmental data. The next step determined whether fish were mature and able to participate in migration, or were immature and would remain in rearing areas. Fishing occurred next, with selection of those fish large enough to be caught by the fleet. From these were calculated the numbers, weights, landings and discards. The last step calculated the

Figure 11. Flow chart of the computer simulation model (ENGLSH) of female English sole in the Columbia Vancouver International North Pacific Fisheries Commission areas.



numbers and weight of the year's survivors and returned these to the beginning of the next year to be simulated.

Geographic Constraints

The physical boundaries of the models were those of the INPFC Columbia and Vancouver statistical areas (Figure 1). The sub-units of population simulated were the four PMFC statistical areas. These four sub-populations or sub-stocks were modeled separately because of area-specific fisheries and biological characteristics. The sub-stocks were treated separately during all computations illustrated in Figure 15 except for migration which dispersed fish into PMFC Areas according to annual migrational patterns.

Temporal Constraints

All calculations were done in the simulation model on an annual time resolution. This assumed the population parameters in the model are annual averages and constant over the year. Numbers, length and weight at age, recruitment, and spacial distributions were computed at the beginning of an annual iteration to represent the average annual population for the ensuing year. The catch, fishing mortalities and natural mortality are assumed to take place simultaneously throughout the year (January through December).

Recruitment in The Simulation Model

Recruitment (tp) as referred to in this study is "the process in which young fish enter the exploited area and become liable to contact with the fishing gear" (Gulland 1969), or the process in which young fish "enter the area where fishing is in progress" (Beverton and Holt 1957). Biological information suggests that English sole enter the exploited area during their second year of life (age 1+); however, estimates of numbers of age-one through age-three fish or natural mortality for these ages were not available. Recruitment in the following section refers to numbers of age-four fish (fish beginning their 5th year of life) entering the exploited biomass.

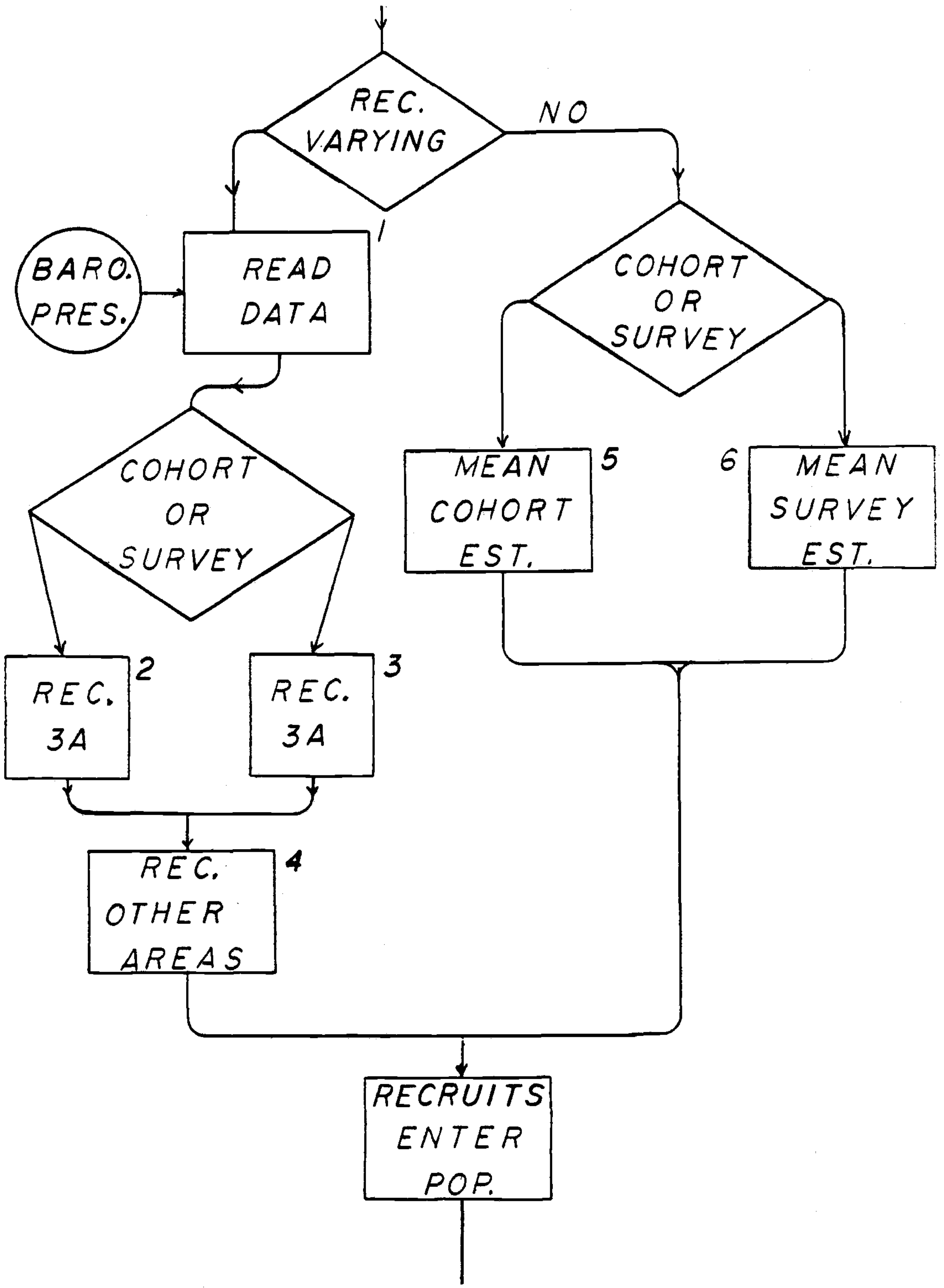
The recruitment section of the simulation model was developed to provide measurement of the effects of varying recruitment and to scale the model to allow estimates of MSY for the Columbia and Vancouver management area. Given the recruitment estimates available from cohort analysis (Hayman 1978), ODF&W groundfish surveys (unpublished manuscript, R. L. Demory, Newport, Oregon, ODF&W offices) and as a function of barometric pressure (Hayman and Tyler 1980), the logical flow for recruitment in the simulation model was conceptualized as in Figure 12.

The recruitment section logic offers a choice of four regimes, mean (Figure 12, step 5) or annually varying (step 2) cohort analysis derived estimates, or mean (step 6) or annually varying (step 3) survey (ODF&W) derived estimates. The cohort-based estimate of varying recruitment (step 2) for Area 3A uses the functional model, (Point A) of Hayman and Tyler (1980). Their model is

$$\ln(R) = 5.60 + (.00712)x(i) \qquad (7)$$

where ln(R) is the natural log of thousands of age-four fish in PMFC 3A, and x (i) is mean barometric pressures from September and October year (i). This equation was log transformed and the decimal place of

Figure 12. Flow chart of English sole recruitment process in the computer simulation model (ENGLSH).



the nonexponential constant moved to the right to change the estimate from thousands to unit numbers of fish. The transformed model is

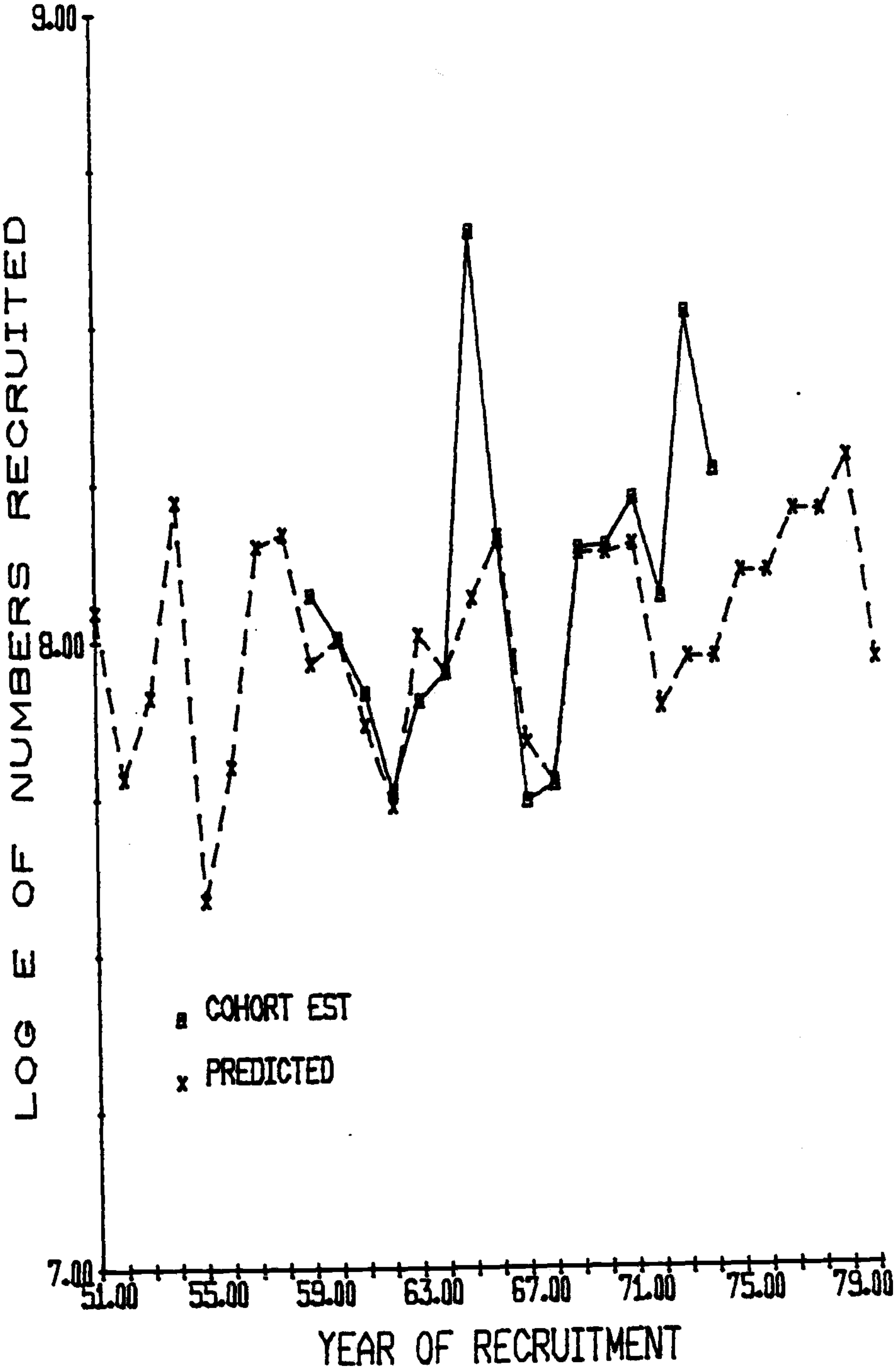
$$Rc(t) = 270426.41\ e^{.00712(baro(t-T)} \qquad (8)$$

where Rc(t) is the number of age-four female English sole in Area 3A at year (t) and baro(t-T) is the sum of monthly mean barometric pressures for September and October from 46' N 124' W at time t-T where t is the simulation year and T is four years hence. The 30-year recruitment time-trends for Area 3A are presented in Figure 13 along with the cohort analysis estimates of recruitment for 1959 to 1974. These estimates suggest several consistently strong year classes entering the fishery during the early 70's or a positive divergence of the cohort estimates from the predicted model.

The mean cohort-based recruitment estimate for Area 3A was calculated from the 30 years, 1951 to 1980, "predicted" by the Hayman-Tyler model (equation 8). Use of this model allowed standardization of the mean and the variations of recruitment in the simulation model to the thirty-year data base rather than the eleven years from Hayman's cohort analysis. It allowed direct comparison of yields with varying and mean recruitment estimates.

To attain annually varying survey-based recruitment estimates for PMFC Area 3A, the Hayman-Tyler model (equation 8) was adjusted by a constant. This constant was the difference between ODF&W groundfish survey and the Hayman-Tyler predictions for the same years and area. The survey estimate recruitment at 3,504,000 in September was adjusted to numbers in January (4,751,000) using negative exponential survival

Figure 13. Comparison between natural logrithms of cohort estimates of English sole year-class strength and year-class strength as predicted from Hayman-Tyler (1982) barometric pressure model.



with Z = .43 (Demory et al. 1976). The resulting proportional difference was 1.422 and equation 8 becomes

$$Rs(t) = 1.4225\ (270426.41\ e^{.00712(baro(t-T))}) \qquad (9)$$

where Rs(t) is the survey-based number of age-four fish recruited to PMFC Area 3A, and e and baro(t-T) were explained above. This model provides survey-based varying (Step 3) recruitment estimates from the same 30-year data base and a survey-based mean recruitment.

The recruitment estimates for Area 3A were expanded using relative abundances between PMFC areas observed during ODF&W ground fish surveys 1971 to 1976 (Table 7). The general model conceived was a proportional adjustment relative to these (Table 7) abundances. These figures were somewhat complicated by the logistics of these data collections. Areas 3B, 2C, and 2B were surveyed in their entirety during the years listed (Table 7); however, the southern half of 3A was surveyed in 1971-73 and the northern in 1975-76. To adjust for the among-year environmental variability, the following expression was conceived,

$$Rs^*(j,t) = Rs(j,t) + \frac{R3A - R3A(t)}{R3A} \times Rs(j,t) \qquad (10)$$

where Rs*(j,t) is survey recruitment estimates for PMFC Area j for year t with environmental variation removed, R3A is mean recruitment for Area 3A for years 1959-1980 from the Hayman-Tyler model (equation 9), R3A(t) is predicted recruitment in PMFC Area 3A also from the Hayman-Tyler model for year t, and Rs(j,t) is the ODF&W estimated recruitment for PMFC Area j in year t. These adjusted estimates,

Table 7. Estimates of thousands of age-four female English sole by method of analysis and Pacific Marine Fisheries Commission Area (PMFC).

PMFC Area	SURVEY'@' 1971-76	SURVEY'&' 1971-76	COHORT'*' 1951-80	SURVEY'+' 1951-80
3B	2573	2300	2279	3291
3A	3504	3161	3102	4482
2C	2582	2410	2286	3303
2B	2099	2289	1858	2685

'@' Oregon Department of Fish and Wildlife (ODF&W) groundfish survey biomass estimates for September during years 1971 through 1976.

'&' ODF&W estimates adjusted for between-year environmental variability, using Hayman-Tyler (1982) barometric-pressure model.

'*' Mean cohort-based estimates for PMFC Area 3A from Hayman-Tylers model for simulated years 1951 to 1980, adjusted to remaining PMFC Areas using proportional differences of survey estimates.

'+' Mean survey-based estimates adjusted as described in '*'.

averaged, produced the single estimate of relative abundance for years 1971 to 1976.

The recruitment estimates for Area 3A were expanded to PMFC Areas 3B, 2C, and 2B using the adjusted abundance estimates from ODF&W (Table 7) and assuming that these relative abundances held constant within the simulated area and time span. It appeared that this population (Vancouver-Columbia) met these assumptions as there were no significant trends in the cohort estimates of population (Figure 13) or commercial catch (Table 1). The model used to extend recruitment estimates over PMFC areas is

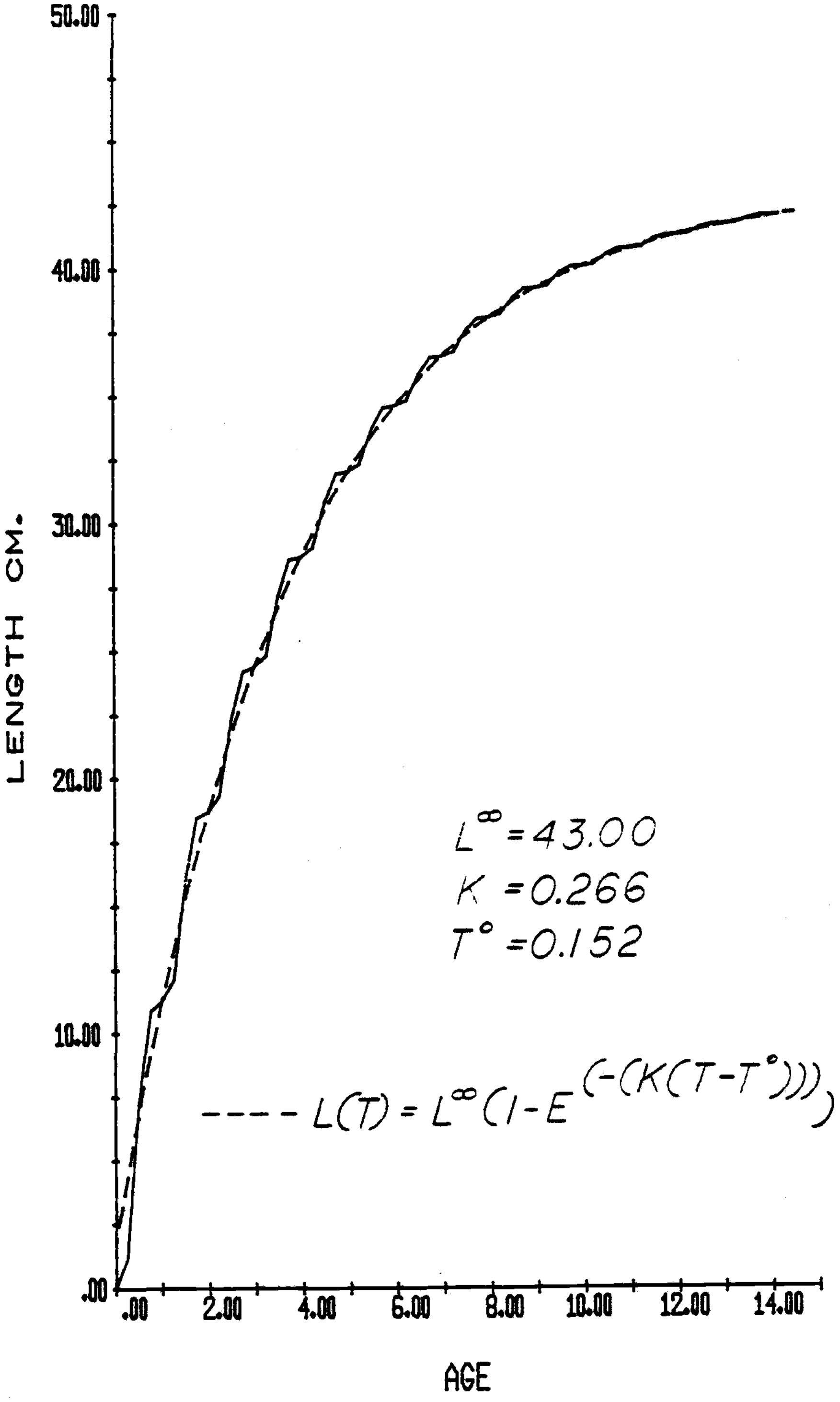
$$R(j,t)=Rs^*(j,t) + \frac{R3A(t)-R3A}{R3A} Rs^*(j,t) \qquad (11)$$

where R(j,t) is the number of recruits in the PMFC area j at year t and Rs*(j,t), R3a(t) and R3A are the same as in equation 10. Equation (12) was used to estimate mean and varying numbers of recruits for Areas 3B, 2C, and 2B at Steps 4, 5, and 6. The mean recruitment for PMFC areas 3B, 3A, 2C, and 2B for cohort- and survey-based estimates are presented in Table 7.

Growth in the Simulation Model

Growth, or length at age, for English sole has been historically described using a Von Bertalanffy relationship. This relationship provides estimates of length over continuous time as illustrated by the graph of Kreuz's (1978) Von Bertalanffy length-age relationship for female English sole off PMFC Areas 3A and 2B (Figure 14).

Figure 14. Von Bertalanffy length-at-age relationship for female English sole off Oregon, with (solid line) and without (dashed line) seasonal variation.



Kreuz (1978) and El Sayed (1959) observed that English sole experienced seasonal variations in growth rates in their respective areas of study. If the seasonal variation in growth (equation 6) is combined with the Von Bertalanffy length-at-age, it produces a new continuous representation of length-at-age also illustrated in Figure 14. Seasonal growth affects yields from a model with annual resolution if the fishery timing is not constant or symmetrical over the year. As an example, if the fishing were concentrated during the first quarter of the year and the traditional Von Bertalanffy expression were used to estimate length at anniversary ages (i) plus a quarter year (i.25) then resulting population biomass and yield would be overestimated. This is illustrated by Figure 14 where less than ten percent of the growth has occurred during the first quarter whereas the traditional Von Bertalanffy expression, the dashed portion of Figure 14, would estimate length at age (i.25) approximately twenty five percent of annual growth. The converse would also be true if the fishery were concentrated in the last quarter of the year. Consequently Kreuz's seasonal variation was incorporated in this growth model to estimate more accurately the yields from the four PMFC areas modeled, as temporal distribution of effort in these fisheries was not equal.

To account for annual deviations in growth observed by Kreuz et al. 1982, the oscillating curve (Figure 14) must be displaced by some environmentally determined amount, and this resultant growth or length-at-age accumulated over years. This means a cohort may maintain a positive or negative deviation from average length-at-age for several years as a result of a single large deviations in growth, or several consecutive small deviations in the same direction.

Average Annual Length-at-Age

The growth models previously discussed all assume growth is a continuous process; however, to model the somatic growth on an annual time resolution requires estimates of average annual length at age. To accommodate this, a difference approximation (Figure 15) is used, where each step represents an average annual length at age over that year. The location of these steps was determined according to change in bottom temperature and seasonally adjusted to accomodate the timing of the fishery in each PMFC area. With this in mind, along with the goals of providing estimates of the effects of annually varying and seasonal growth, the logical flow for the growth algorithm was conceptualized (Figure 16).

This logic began by computing initial annual length-at-age (Step 8) using the Von Bertalanffy expression,

$$L(t)=Lmax\left(1 - e^{k(t-tnot)}\right) \qquad (13)$$

where Lmax = 43.00 cm., k is .266, t is fish age in years and tnot is -0.152 (Kreuz 1978). This is used to compute annual anniversary length and growth at age. This is followed by offering a choice (Step 8) of environmentally varying (Steps 11 through 13) or fixed annual growth (Steps 9 and 10).

To compute annual average growth and length-at-age (Steps 9-10 and 14-16), Kreuz's seasonal growth equation 6 (Step 14) adjusts the growths to coincide with the timing of the fishery by PMFC area. It was assumed that the distribution (temporal) of effort among PMFC areas was symetrical. This allowed the use of the number of days till half

Figure 15. Difference approximation of length-at-age relationship for female English sole off Oregon.

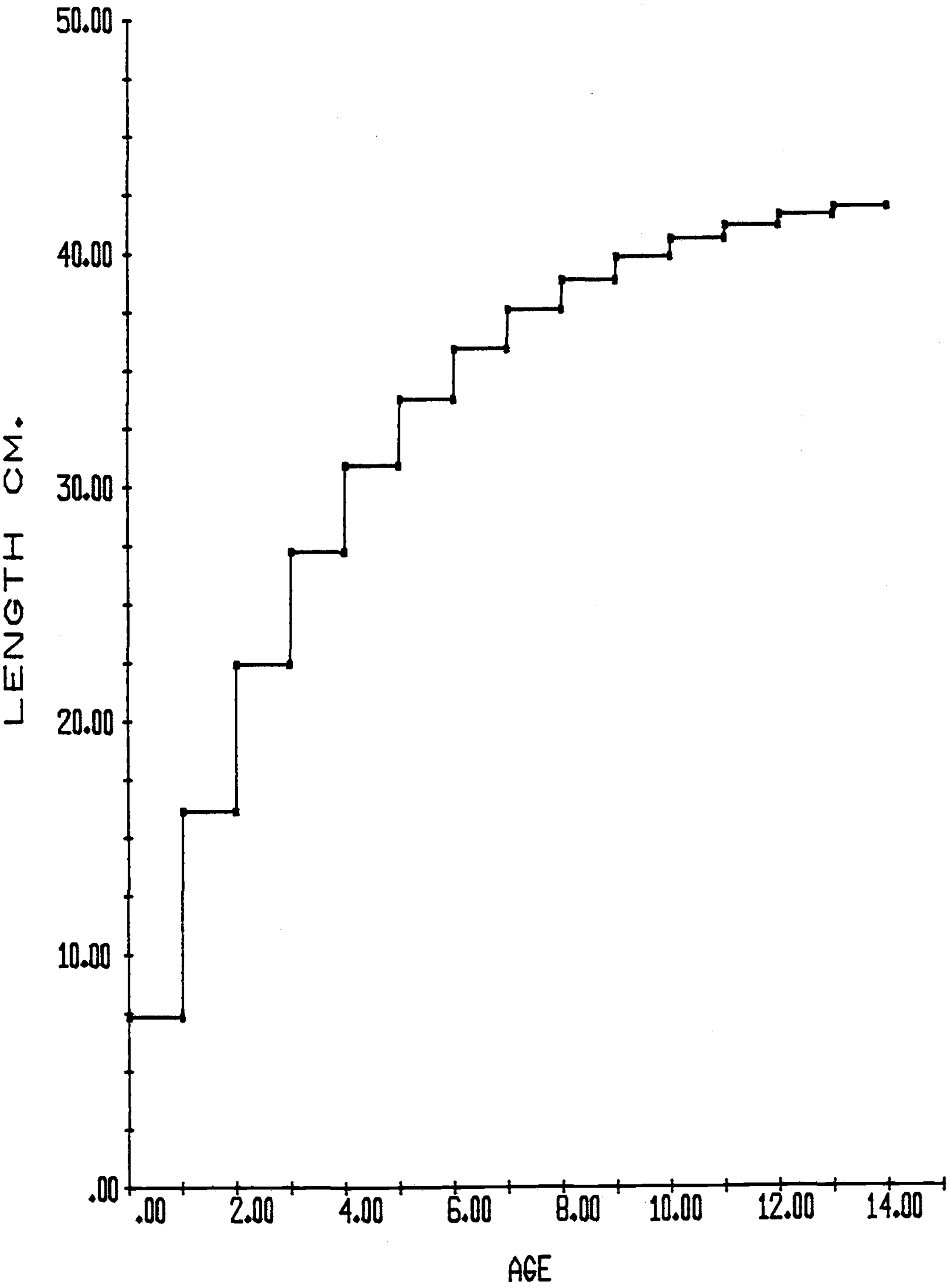
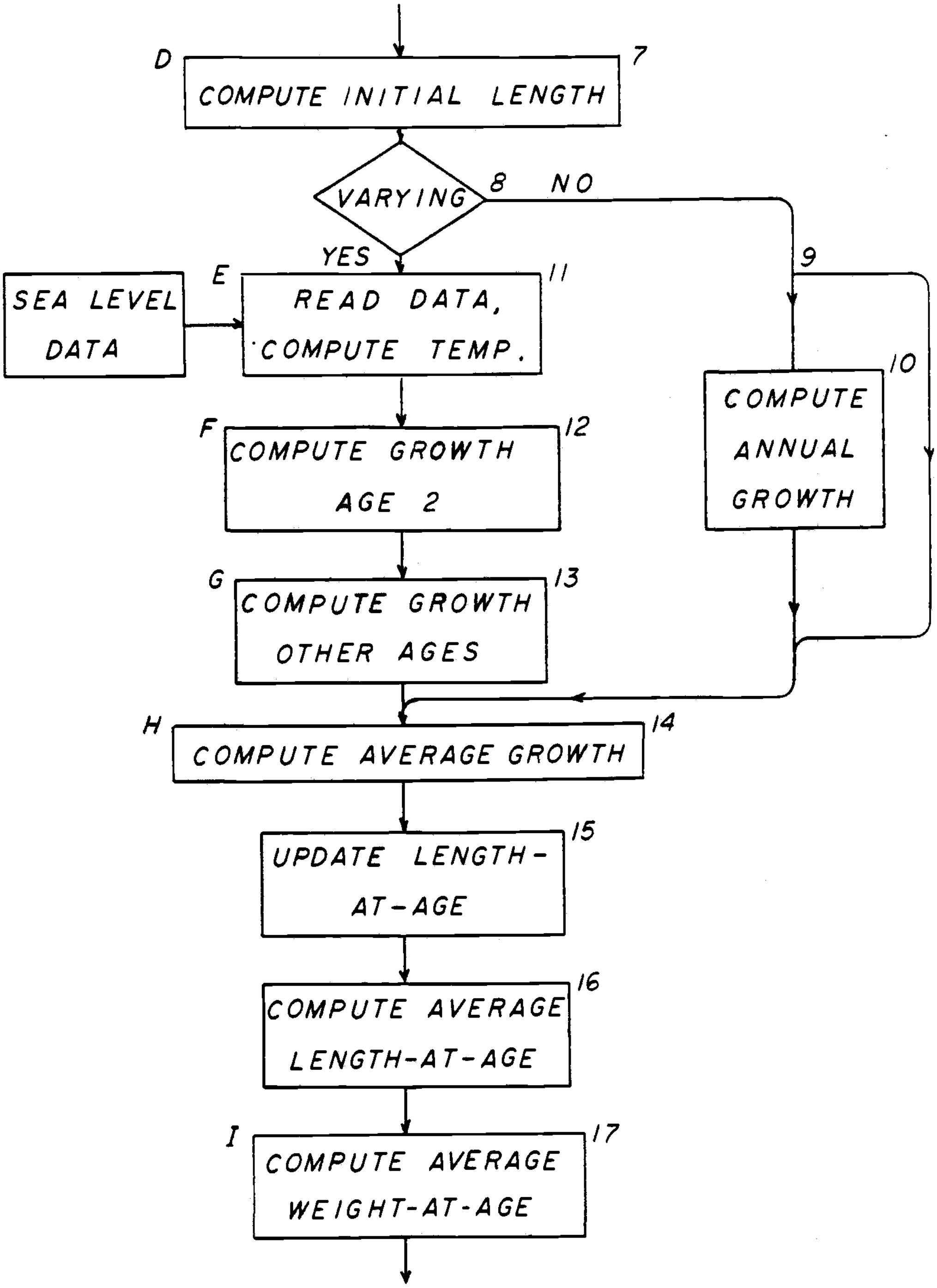


Figure 16. Flow chart of the English sole growth process in the computer simulation model (ENGLSH).



of that year's catch was landed to estimate that portion of annual growth (equation 6) that would coincide with the PMFC area's fishery. This was used to estimate average area-specific annual growth which was combined (Step 15) with the previous year's final length to estimate the year's average length-at-age (Step 16) Table 8.

Annual Variation in Growth (Length-at-Age)

Variable growth was computed using 30 years (1951 to 1980) oceanographic data (Point E, Step 11) and the varying growth model of Kruez et al. (1982)(Step 12, Point F). Their equation is

$$VG(t) = b + a(BT(t)), \qquad (14)$$

where VG(t) = the annual growth increment(cm) for age-one female English sole in year (t), b=17.06 and a=-1.32 and BT(t) is monthly mean temperature in degrees centigrade at the 100-meter isobath off Newport, Oregon, at year (t). Bottom temperature is a function of sea level (Step B) as expressed by

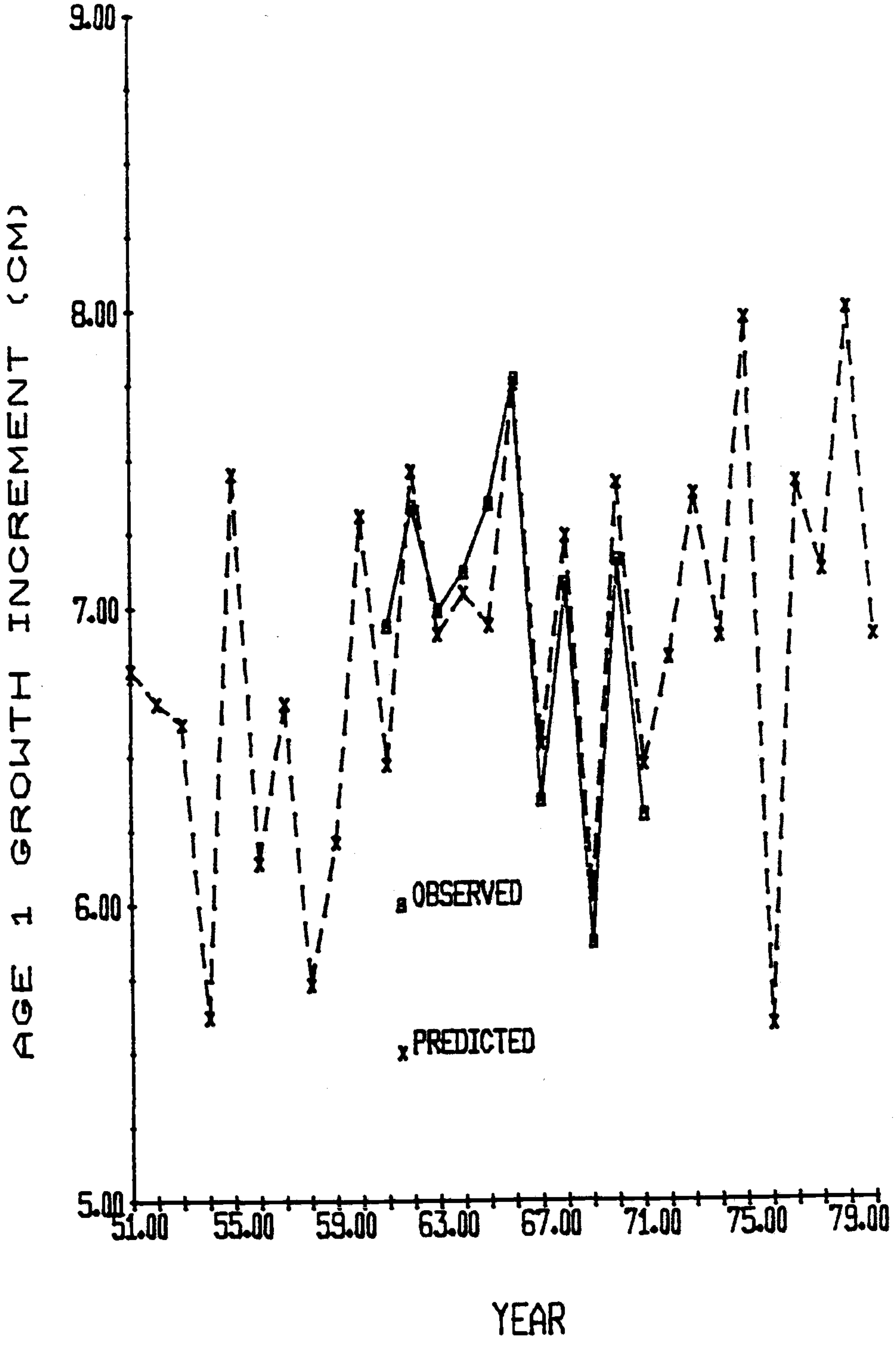
$$BT(t) = b + a(SL(t)/c), \qquad (15)$$

from Kruse (1980), where BT(t), (a = 9.0841) and (b = -9.1761), (c) converts sea level in feet to meters, and SL(t) is monthly mean sea level in June from Neah Bay, Washington in feet below mean low low water on year (t). Results from the varying growth model for the 30 years of data 1951 to 1980 are presented in Figure 17 along with the eleven years of observed growth increments for age one for years 1961 to 1971. Comparison of these data suggest that the model estimated annual variation with a considerable degree of accuracy. It can be

Table 8. Average annual total length (cm) and weight (gm) at age ,by Pacific Marine Fisheries Commission area, of female English sole in the simulation model (ENGLSH).

	Pacific Marine Fisheries Commission Areas							
	3B		3A		2C		2B	
AGE	LEN.	WT.	LEN.	WT.	LEN.	WT.	LEN.	WT
0	8.17	4.80	7.33	3.45	8.44	3.10	8.53	3.22
1	16.67	42.23	16.13	38.19	16.85	32.59	16.91	32.98
2	22.82	109.97	22.40	103.91	22.96	93.32	23.00	93.87
3	27.53	194.82	27.21	188.00	27.64	175.35	27.67	176.00
4	31.15	283.90	30.90	277.02	31.23	265.61	31.25	266.19
5	33.91	367.75	33.73	361.83	33.96	353.19	34.00	354.61
6	36.04	442.78	35.89	437.19	36.08	433.95	36.10	434.76
7	37.66	506.28	37.55	501.79	37.70	503.85	37.71	504.30
8	38.91	559.26	38.82	555.33	38.94	562.46	38.95	562.95
9	39.86	601.93	39.80	599.17	39.89	610.50	39.89	609.98
10	40.60	636.64	40.55	634.25	40.61	648.79	40.62	649.33
11	41.16	663.78	41.12	666.01	41.17	679.72	41.17	679.72
12	41.59	685.15	41.56	687.99	41.60	704.16	41.60	704.16
13	41.92	701.85	41.90	700.93	41.93	723.34	41.93	723.34

Figure 17. Comparison between observed annual growth increments of age-one female English sole off Oregon and annual growth increments as predicted from the Kreuz et al. (1982) bottom temperature model.



that this accuracy will hold for the years preceeding and following the observed growth. The next step (13) converted growth of age one to the older ages. Kreuz et al. (1982) determined that the annual variations in growth increment were synchronous over ages one through eight. Consequently, the growth for succeeding ages was computed using proportions of the growth of age-one fish. The next step (15) in the growth algorithm involved keeping a record so the annual deviations in growth accumulate over time. This was accomplished by keeping track of annual length-at-age and updating this record annually with that year's increment in annual growth.

Weight-at-Age

The last step (17) converted length to weight-at-age. The four length/weight studies in the literature for English sole off Oregon and Washington used the allometric growth equation,

$$W = aL^{b} \qquad (16)$$

where, W is weight, L is length, (a) is a constant and (b) is relative growth constant. The estimates selected for this simulation are those of Demory et al. (1975) and Barss et al. (1976) which were made from samples taken during the groundfish surveys conducted during September 1971 to 1976 from PMFC Areas 2B, 2C, 3A, and 3B. Both these authors examined portions of PMFC 3A; however Barss's survey (1975-76) covered the majority of 3A. Consequently, his estimates (a=.007965, b=3.04795) were used for 3B and 3A, and Demory's (a=.0021984 and b=3.4004) for 2C and 2B. The average annual weight at age by PMFC Area are presented in Table 8.

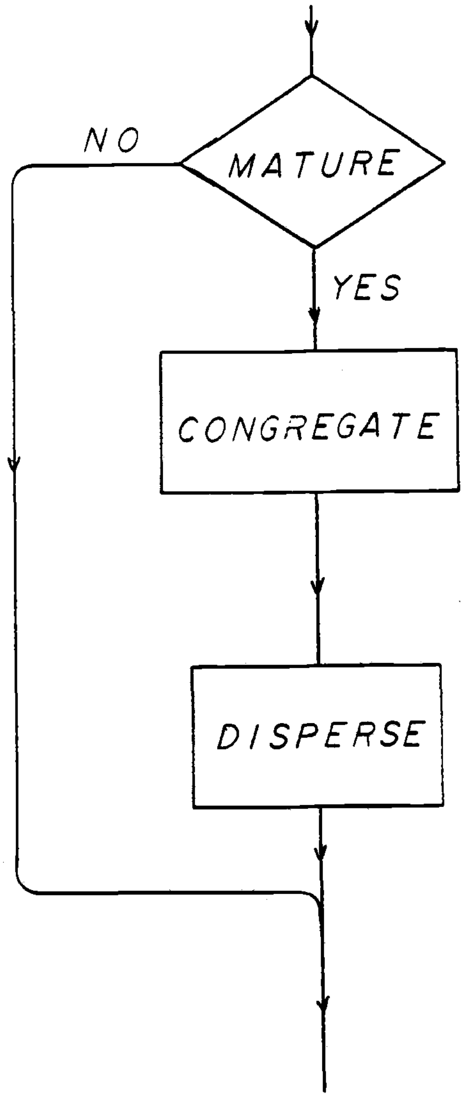
Migration in the Simulation Model

Migration in this simulation was handled at two levels, the Columbia-Vancouver management unit as the maximum range, and the PMFC areas as sub-units. The Columbia-Vancouver management area was the geographic limit of this simulation and was assumed closed or with balanced emigration and immigration. Personal communications with R. L. Demory and early tagging reports (Anonymous 1960) which estimate emigration and immigration rates at less that five percent support this assumption. The migration within the Vancouver-Columbia area was studied by Ehrhardt (1973) and Golden et al. (1979), and describe general northward movement in winter and spring followed by southern movement in the fall. To simulate this migration on an annual time resolution required simplification of the movement into mature fish congregating in a common spawning area at the beginning of the year and then being proportioned to PMFC areas (Figure 18) for ensuing fisheries. The redistribution proportions were determined during model validation by comparing the simulated output (yield by area) with the mean commercial catch statistics, by operating the model near mean levels of recruitment, growth, and mortality until simulated and actual landed catches were about equal.

Maturity

Mature and immature fish were separated using a length-specific equation fit to the percent-mature-at-length data of Harry (1959). The equation used was

Figure 18. Flow chart of the English sole migration process in the computer simulation model (ENGLSH).



$$M(L) = 1 - \frac{1}{1 + e^{-(M1-M2)L}} \qquad (17)$$

where M(L) is percent maturity by length, M1 and M2 are parameters (L) is fish total length (cm). Unweighted NONLINEAR regression was used to fit percent-mature-by-length equation using the previously discribed procedures. Parameter estimates along with the observed and predicted relationships are presented in Figure 19.

Yield in the Simulation Model

Simulated numbers and weight of the commercial landings from the population were the most important outputs. They provided measures of the effects of age-specific fishing and discarding mortalities, varying growth and recruitment rates, migration and estimates of the portion of the population available to society. Yields also provided the majority of comparative information for model validation.

The logic for the fishery portion of the simulation model (Figure 20) begins by offering selection of area-specific fishing mortality rate F. The next logical step (21) offers knife-edge or length-specific (ogive) selectivity, catch utilization, and discards. Knife-edge selectivity, catch utilization, and discards all operate at lengths where 50 percent are selected or retained, utilized or discarded (Step 22). There is no discard mortality (Figure 21) when the 50 percent utilization length is greater than or equal to the 50 percent selectivity length (e.g., fleet is utilizing or landing all fish caught). For those situations where fleet selectivity length is less than fleet utilization length (Figure 21), there is discard

Figure 19. Percent maturity with length for female English sole off Oregon, form data of Harry (1959).

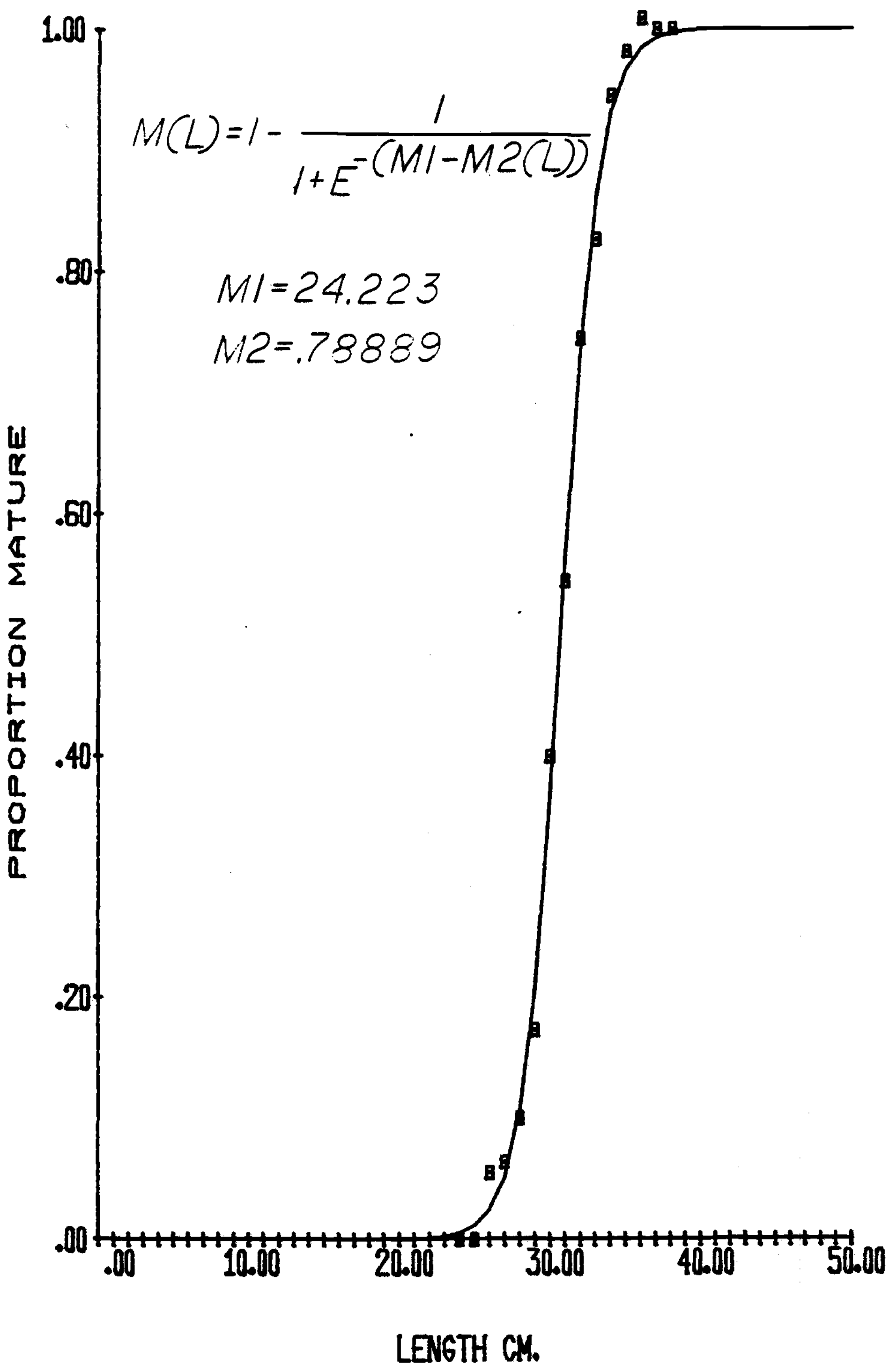


Figure 20. Flow chart of English sole fishery process in the computer simulation model (ENGLSH).

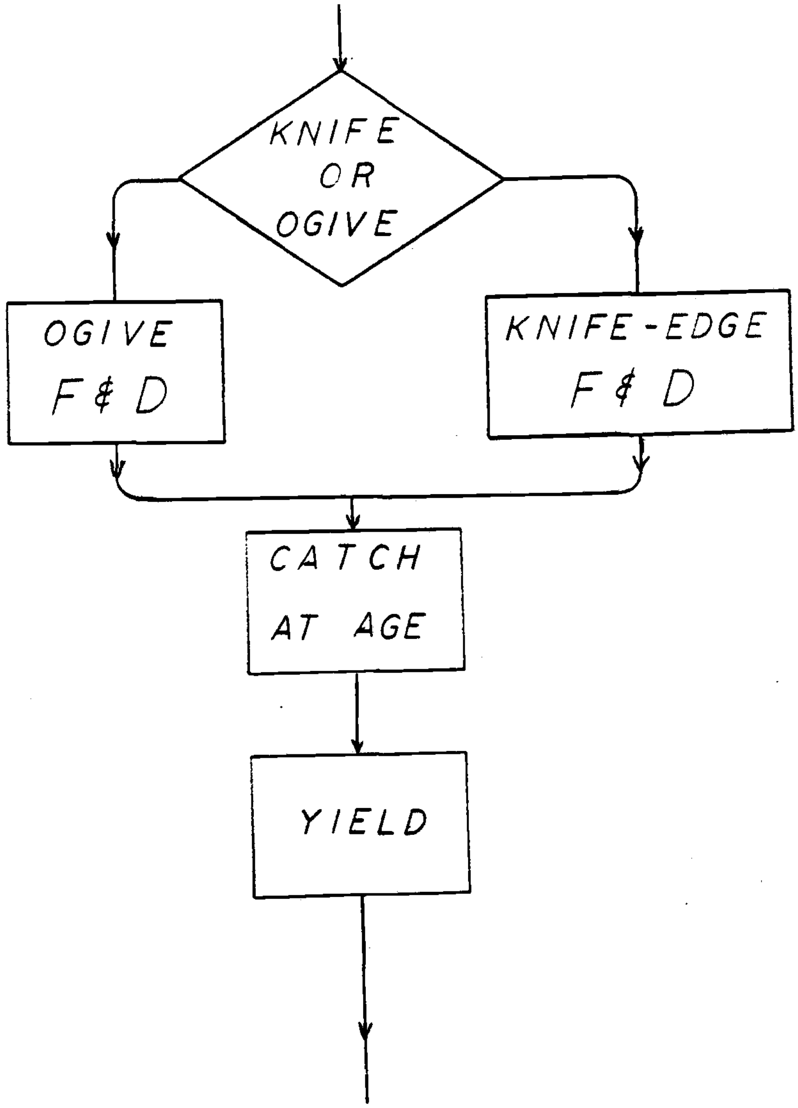
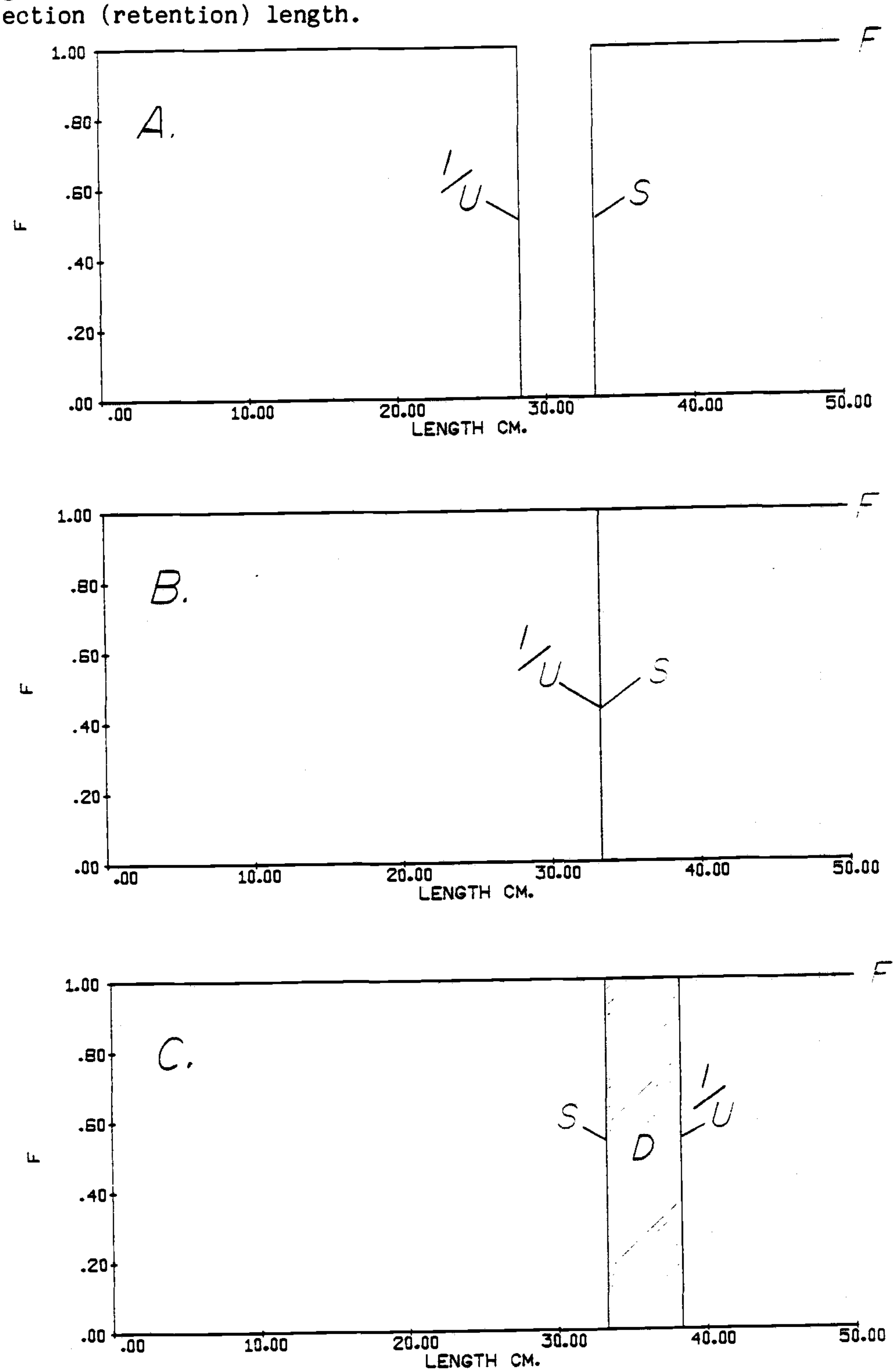


Figure 21. Illustration of knife-edge fishing and discard mortality with length for three possible situations when 50 percent utilization length is less than (A), equal to (B), or greater than (C) 50 percent selection (retention) length.



mortality as illustrated by the double cross-hatched portion of the figure.

When logistic fleet selectivity and catch utilization are switched on, age-specific fishing and discard mortalities are calculated using equations 3 and 5 with the length-at-age, area, and year included. Equation 3 then becomes age-specific fishing mortality,

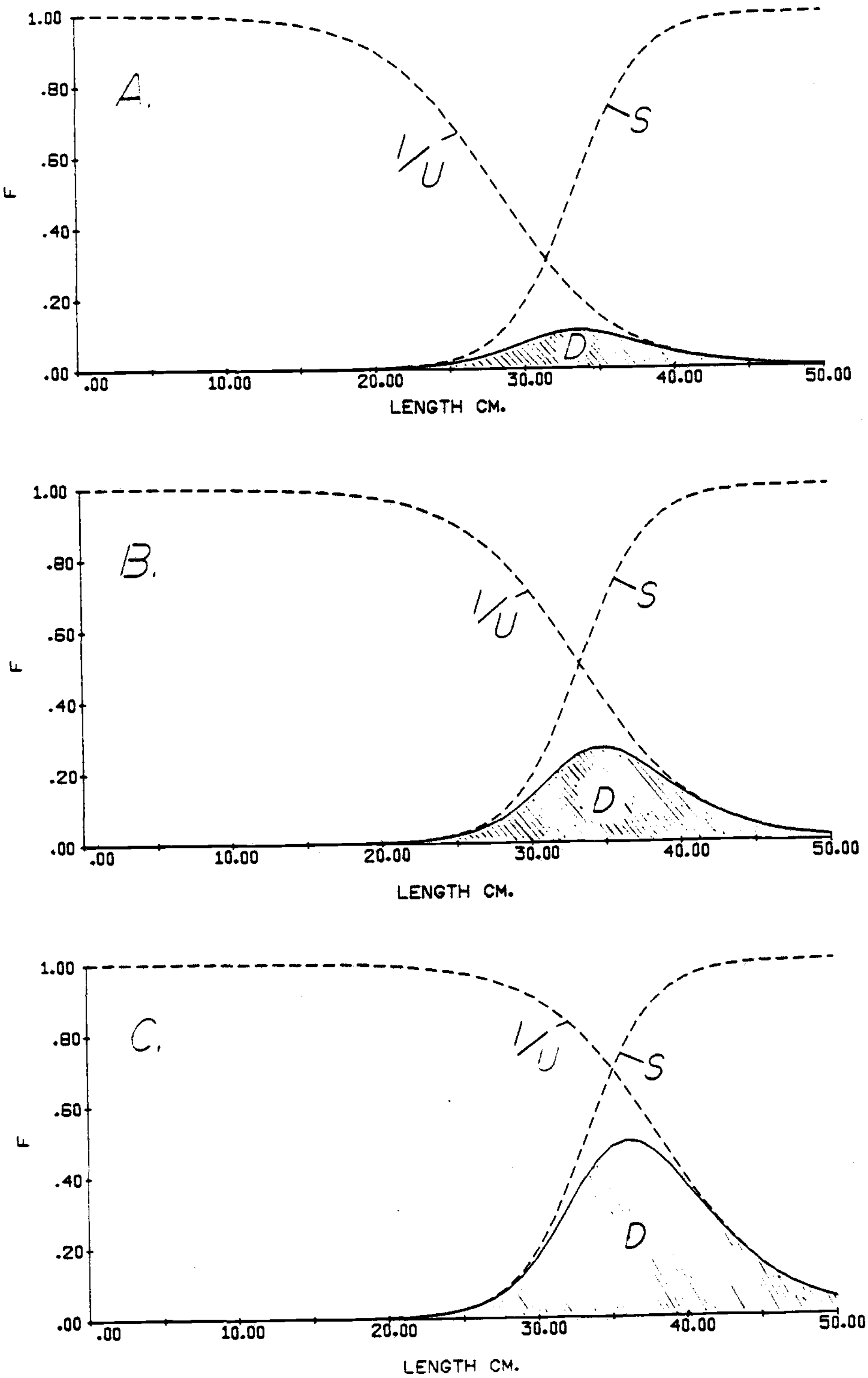
$$F(i,j) = s(i,j))u(i,j)F(j) \qquad (18)$$

where F(i,j) is age-specific(i) and year-specific(j) fishing mortality, s(i,j) and u(i,j) are as described earlier, and F(j) is the year-specific(j) instantaneous fishing mortality rate. Expression 5, age-specific discarding mortality is incorporated as follows:

$$D(i,j) = a(s(i,j)d(i,j)F(j) \qquad (19)$$

where D(i,j) is instantaneous the age-specific(i) and year-specific(j) discard mortality, d(i,j) is equation (4) subscripted for age(i) and year(j), and a, s(i,j) and F(j) are proportion of dead discards, age(i) and year(j) fleet selectivity and annual(j) instantaneous fishing mortality as described before. The effects of selectivity and utilization curve on discarding mortality are illustrated in Figure 22. The largest discarding mortality occurs when utilization is to the right of the selectivity ogive (Figure 22), coinciding with a situation in which sizes acceptable to the processor are larger than fleet trawl selectivity. These figures also illustrate that discard mortality is present as long as the selectivity and utilization curves overlap.

Figure 22. Illustration of ogive fishing and discard mortality with length for three possible situations when 50 percent utilization length is less than (A), equal to (B), or greater than (C) 50 percent selection (retention) length.



Yield in numbers (Step 24) is computed using the Baranov catch equation expanded to include age-specific fishing and discarding mortality rates. The equation is

$$C(i,j) = N(i,j) \frac{F(i,j)}{F(i,j) + M + D(i,j)} \left(1. - e^{-(F(i,j) + M + D(i,j))}\right) \qquad (20)$$

where C(i,j)= landed catch in numbers of fish ,N(i,j) is the number of fish and F(i,j), M and D(i,j) are mortality rates described previously. The ((i,j)) denotes that these population parameters are expanded to include age and year, respectively.

Yield in weight is computed (Figure 20., Step 25) with

$$Y(i,j) = C(i,j)\ W(i,j)/c \qquad (21)$$

where Y(i,j) = landed catch in metric tons C(i,j) is as above, W(i,j) is weight of the fish, (c) is a conversion constant from grams to tonnes and (i,j) is as above. Yields are summed over age, area and year so that they are available in numbers and various weights (metric and English) for each PMFC subpopulation and total population (Step 25). Also computed are landed percentage age compositions by PMFC area to simulate state agency sampling for reference and validation of fleet selectivity.

Calculation of Survival

The last step in the model logic removed annual mortalities to determine the portion of the population or stock that would enter its next year of life. This was computed on an annual resolution using the negative exponential survival relationship,

$$N(i,j,k) = N(i,j,k-1)\ e^{-Z} \qquad (22)$$

where N(i,j,k) is numbers of fish at age(i), area(j) and year(k) and Z=(F(i,j) + M + D(i,j)).

Equation 22 was used for each of the four PMFC areas, and the resultant survivors were summed over age and area to provide various population system-state variables. Some of these variables included numbers, pounds and tonnes of the population before and after the simulated year. These were included to provide population reference points for model debugging. This completed the model logic for a simulated year after which the flow was returned to the beginning of another year. The fortran version of this model, 'ENGLSH' is listed in Appendix 1.

MODELING EXPERIMENTS

The following is a list of the experiments that were designed for model validation, parameterization, to estimate MSY, and measure the effects on yield of knife-edge and ogive fishing and discard mortality rates, and varying growth and recruitment:

1. Yield contours or response surface analyses with F and M on the x and y axes respectively and yield on the z axis. These simulations illustrate the range of acceptable values for F and M, given estimates of average growth and two recruitment levels.

2. Yield-per-recruit simulations for PMFC Area 3A to select a fleet selectivity ogive that will reproduce ODF&W's catch composition from this area for years 1969-79.

3. Yield by PMFC area with F, M and fleet selectivity from two experiments (a. and b. below) to adjust adult migration within PMFC areas to reproduce average catch statistics by areas, for years 1969-79.

   a. F is assumed to be constant over area.

   b. F in PMFC Area 3B is assumed to be double the others.

4. Four sets of yield-per-recruit simulations to examine age-one versus age-four fish recruited to the fishing grounds, and ogive versus knife-edge fishing and discard mortality.

5. Two MSY estimates, one with each recruitment estimation, both using ogive selection, utilization and discard mortality, migration from validation analysis and average growth

rates.

6. Two series of yield simulations (a. and b. below) to measure effects of varying growth and recruitment;

a. Use of varying recruitment and mean growth.

b. Use of varying growth and mean recruitment.

7. The final series of five yield curves examine the effects of maximum and minimum observed deviations in growth and recruitment. One control curve used mean growth and recruitment; the others used either maximum or minimum growth or recruitment.

MODEL VALIDATION

To meet validation criterion, it was necessary for the simulation model to produce statistics within the .95 confidence interval (C.I.) of the mean commercial catch statistics. These statistics were landed commercial catch-age compositions for PMFC 3A, and landed catches by PMFC area and for the Columbia-Vancouver areas combined. Validation was complicated by the lack of initial point estimates for M, F, D, fleet selectivity and migration rates. A validation procedure was conceived that utilized the population parameter range estimates and the .95 C.I. of mean commercial catch statistics. Catch statistics were restricted to years 1969 to 1979 to eliminate the different age structure of the commercial landings in PMFC 3A previous to 1969. (Prior to 1969 the age composition of commercial landings showed higher percentages of younger, and lower percentages of older fish.) (See Figure 2.)

The general solution for this validation problem was to conceptualize this simulation model as a multidimensional equation with the dependent variable a cloud of yields corresponding to the .95 C.I. of mean commercial landing statistics for 1969 to 1979. This region of acceptable yields restricts the range of acceptable population parameter values (independent variables). This adjusts the simulation model to the current fishery statistics. The separate examination of the two recruitment estimates and removal of migration and fleet selectivity reduce the problem to two three-dimensional yield response surfaces.

The yield contours were obtained from a Fortran V version of ENGLSH which increments (F) and (M) internally to reduce operator and computer time. Recruitment and growth were set at annual averages for years 1969 to 1979. The initial running of the contours used 4.5-inch mesh selectivity and Teneyck and Demory's 1975 ogive for catch utilization and discarding, and dispersal proportions equal to recruitment proportions. The yield matrix output from the two different recruitment estimates were input into PLOTLIB (OSU Computer Center 1980), a FORTRAN contour plotting routine. The x and y axes were also labeled with the range of estimates available for M and Z (Table 5).

To validate fleet selectivity, simulated and commercial age composition catch statistics for PMFC Area 3A (1969 to 1979), were compared for the five mesh size ogives (Figure 8). Selectivity validation acceptance criteria was to have the model reproduce the age compositions within the 95 percent C.I. of observed mean for years 1969 to 1979 on Table 2. Since this process compares sets of age composition as percentages, it was not necessary to have actual numbers of fish at age or recruitment. Commercial catch samples contain traces of ages one through three (Table 2.). Consequently recruitment in this simulation was extended to include age-one fish. Recruitment during these analyses was set at one million age-one fish and it was assumed that M for ages one through four was equal to M for ages four and older. These simulations were made with mean estimates of F and M from a prelimimary response surface analysis, the utilization and discard ogives, and average growth.

The last step in this validation process checked migration, or annual dispersal proportions, by comparing simulated landings with actual landings by PMFC area for the years 1969 to 1979. At acceptable levels, it was necessary that the model reproduce average yields by PMFC area for this ten-year period that were within the .95 C.I. of means observed. ENGLSH was used for these simulations with two separate series run, one with cohort analysis-based recruitment, the other with survey-based recruitment. The other population parameters were average annual growth, best estimates of F and M, and selectivity from the previous analyses.

These procedures were repeated with the results of each step updating the values of F, M, fleet selectivity, and redistribution proportions used in the next simulation run, updating the parameter values used in the next. Final parameter values were arrived at when acceptance criteria were met.

RESULTS

Validation

Initial response surface analysis of F and M (Figures 23 and 24) suggested that M would be in the upper ranges of the estimates (Table 5, p. 20). The final runs (Figures 25 and 26) which incorporated the final fleet selectivity and redistribution proportions suggest M and F of 0.26 and 0.29 respectively for cohort-estimated recruitment (Figure 27), and M and F or 0.35 and 0.26 respectively for survey-estimated recruitment (Figure 25). These final response surfaces for survey-estimated recruitment (Figure 25) still place the acceptable region of M above and in the upper range of observed values, while final cohort-estimated recruitment (Figure 26) places M=0.27 almost midpoint of the range of estimates available.

The 5.5-inch mesh selectivity ogive provided the best representation of fleet selectivity, with only slight (less than one percent) deviation from the .95 C.I. of mean age compositions at ages 2 and 13 (Table 9). Coincidentally, 5.5-inch mesh is the size preferred by the majority of the Oregon Trawl Fleet (R. L. Demory, personal communication, 1982). The discard mortality rate from the 5.5-inch mesh ogive (Figure 27) is less than ten percent of F and half of that observed with 4.5-inch ogive (Figure 10).

The redistribution proportions computed when F was assumed constant over PMFC Areas (Table 10) suggested that the majority, over 60 percent, of the population resides in PMFC Areas 3A and 3B. This observation coincides with the migratory patterns observed by Golden et al. (1979).

Figure 23. Initial response surfaces of yields of female English sole in the Columbia-Vancouver International North Pacific Fisheries Commission areas with F and M on the x and y axes respectively and mean recruitment estimate from Oregon Department of Fish and Wildlife groundfish surveys.

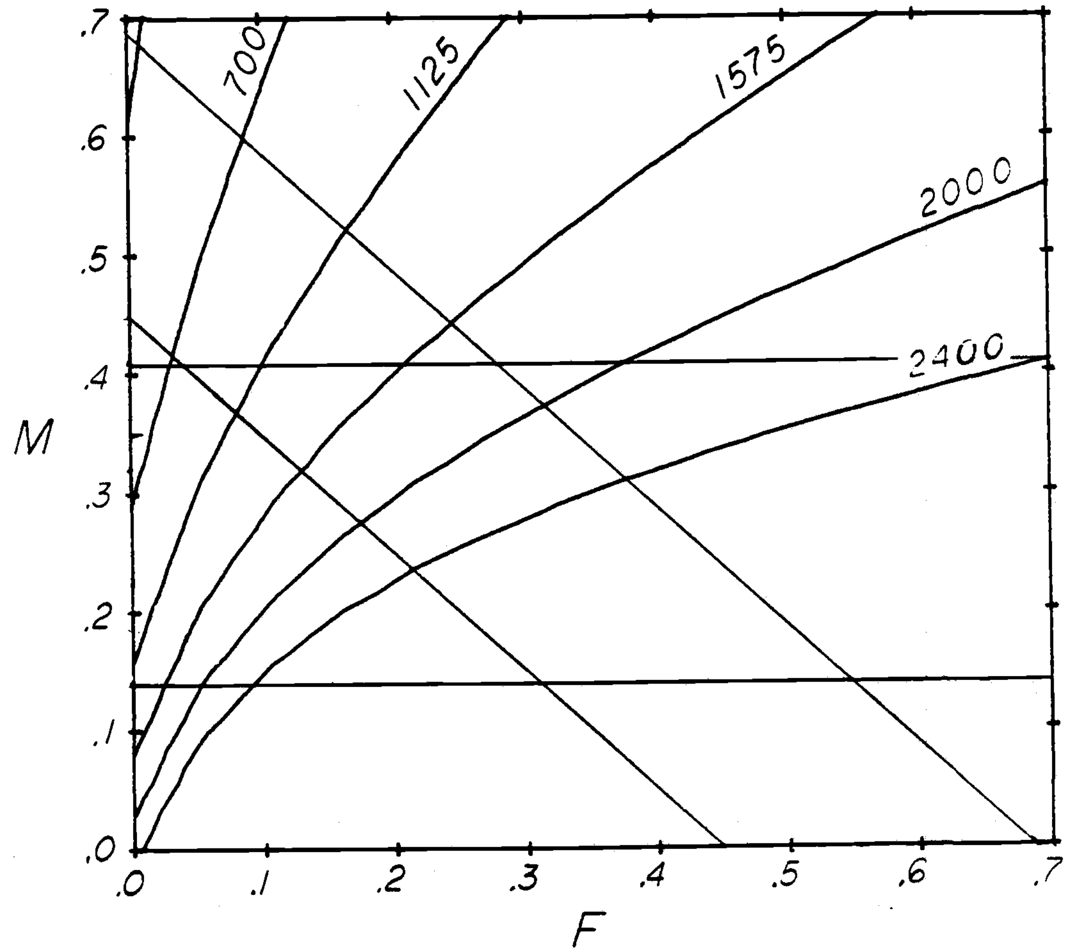


Figure 24. Initial response surfaces of yields of female English sole in the Columbia-Vancouver International North Pacific Fisheries Commission areas with F and M on the x and y axes respectively and mean recruitment estimate from cohort analysis.

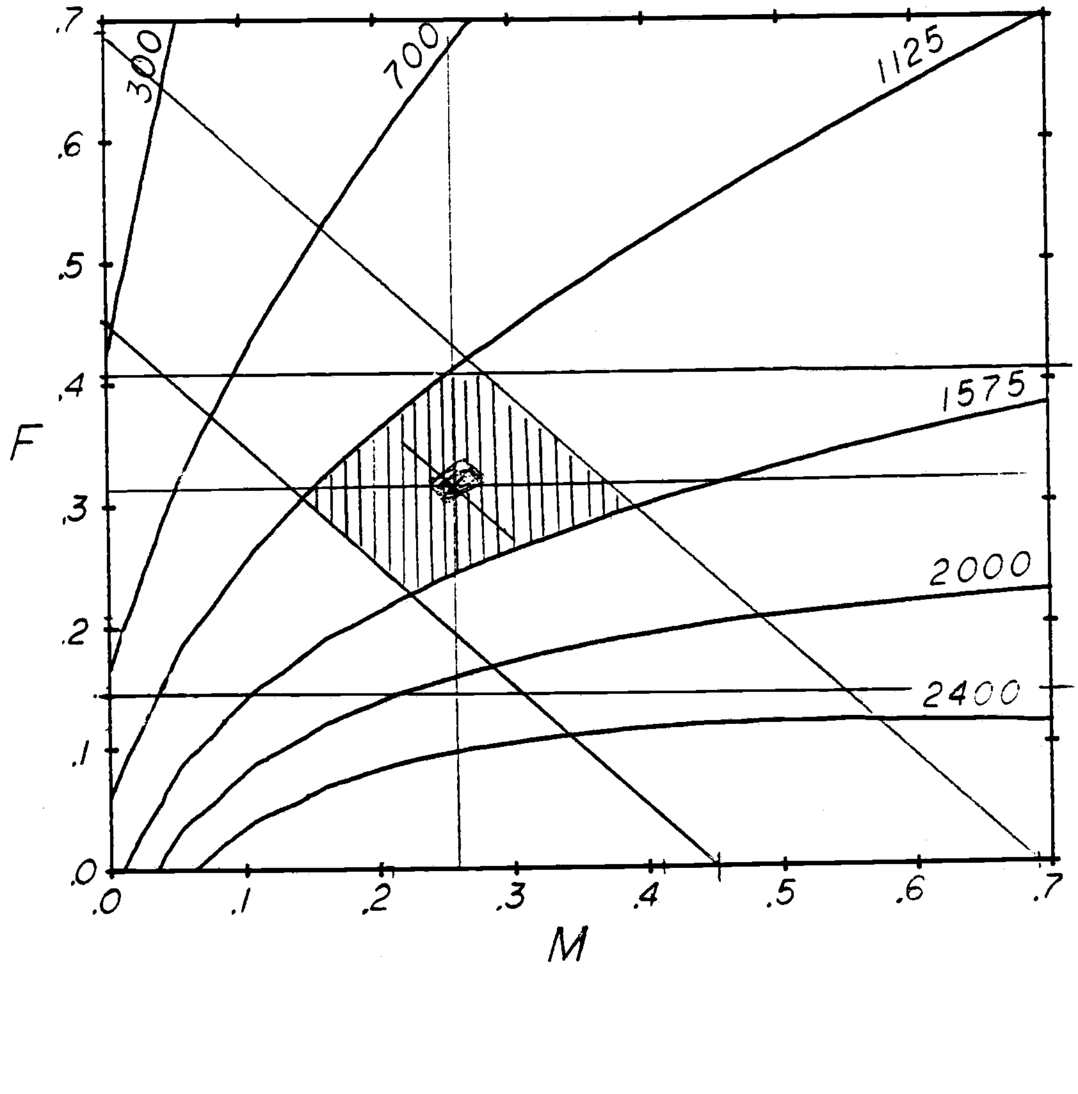


Figure 25. Final response surfaces of Yields of female English sole in the Columbia-Vancouver International North Pacific Fisheries Commission areas with F and M on the x and y axes respectively and mean recruitment estimate from Oregon Department of Fish and Wildlife groundfish surveys.

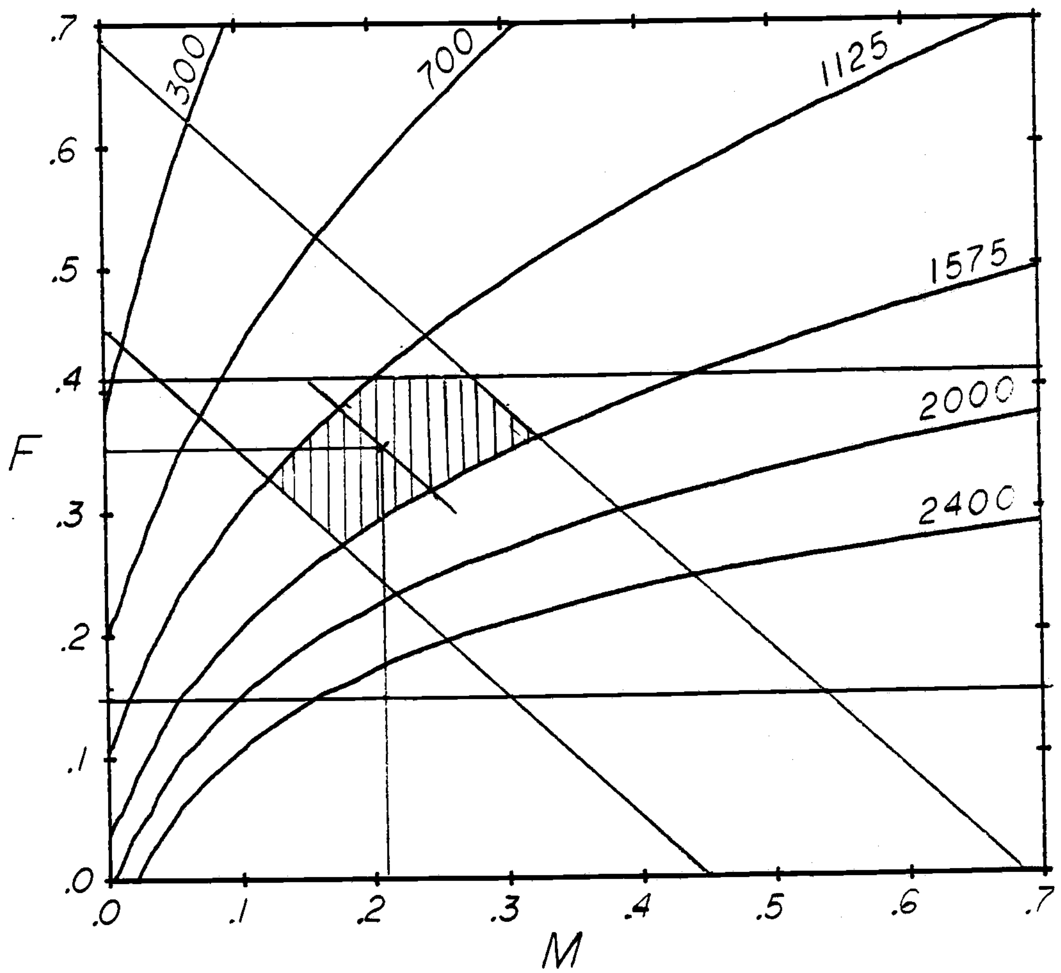


Figure 26. Final response surfaces of yields of female English sole in the Columbia-Vancouver International North Pacific Fisheries Commission areas with F and M on the x and y axes respectively and mean recruitment estimate from cohort analysis.

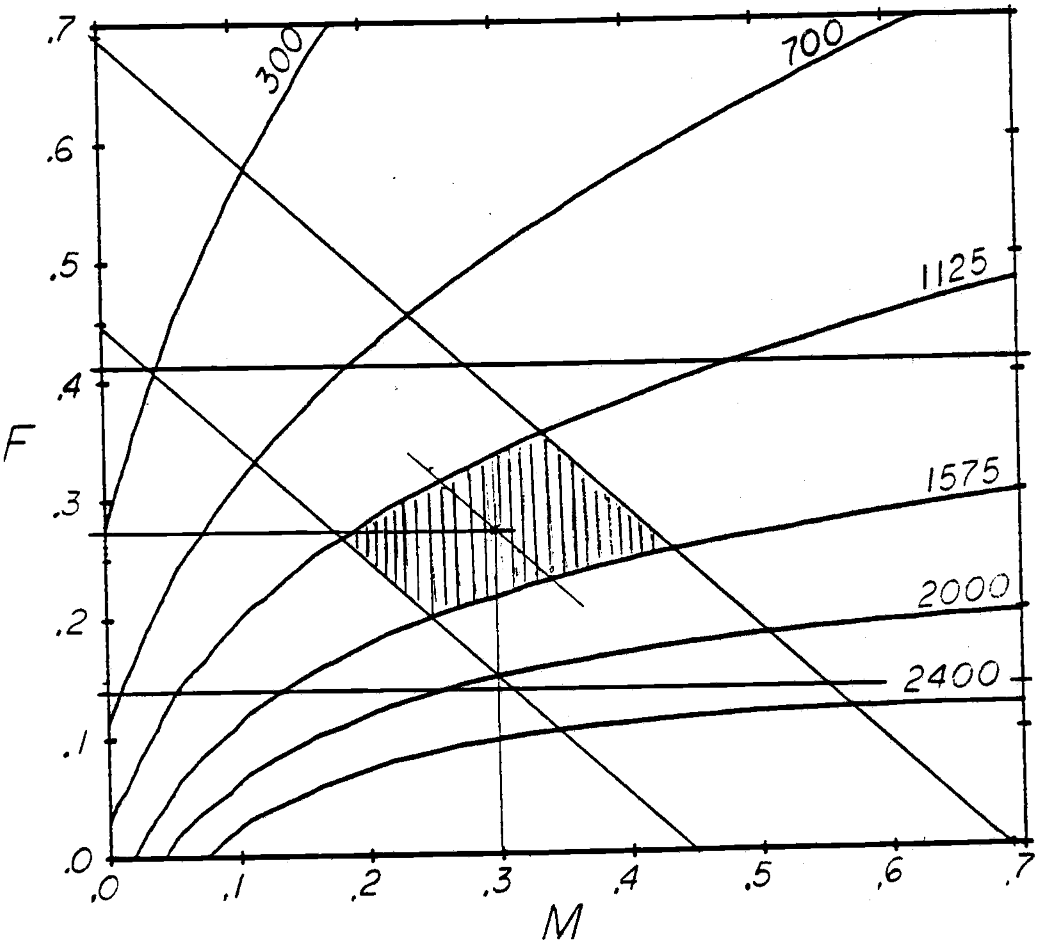


Figure 27. 5.5-inch mesh selectivity, Oregon trawl fleet catch utilization and resultant instantaneous discard mortality by length for female English sole in the Columbia-Vancouver International North Pacific Fisheries Commission Areass, 1969-79.

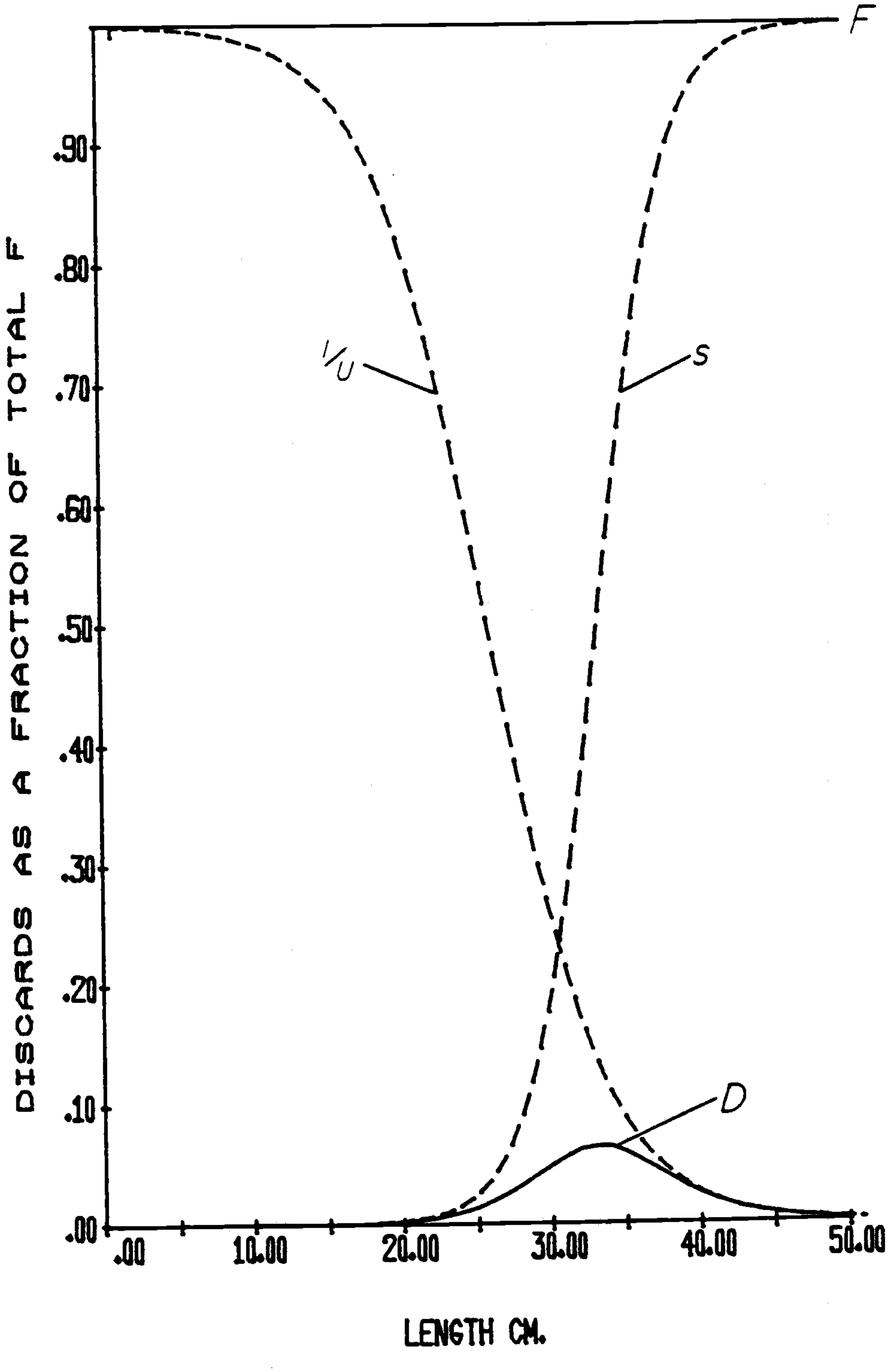


Table 9. Comparison between mean observed age composition of female English sole from Pacific Marine Fisheries Commission Area 3A, years 1969-79, and predicted mean age compostion from the computer simulation model (ENGLSH).

	PMFC AREA 3A		SIMULATED CATCH COMPOSITIONS	
AGE	MEAN%	.95 C.I.	COHORT RECRUITMENT	SURVEY RECRUITMENT
2	0.05	0.06	00.2	00.2
3	03.6	1.5	03.0	03.4
4	14.1	2.6	13.8	14.5
5	24.5	2.1	23.5	23.6
6	20.4	2.1	21.8	21.4
7	15.0	1.4	15.3	14.9
8	10.0	1.9	9.6	9.4
9	6.1	1.2	5.9	5.6
10	3.1	0.5	3.4	3.3
11	1.6	0.8	1.9	1.9
12	0.8	0.4	1.1	0.6

Table 10. Mortality rates, migration, and fleet mesh size estimates from validation of the simulation model (ENGLSH), for female English sole in Pacific Marine Fisheries Commission Statistical Areas, 3B, 3A, 2C and 2B.

PARAMETER	SIMULATION RUNS				
	INITIAL		FINAL		F = OVER AREA
	COHORT	SURVEY	COHORT	SURVEY	COHORT
F	.26	.31	30	21	F(3B)=.406 F(3A)=.173 F(2C)=.167 F(2B)=.220
M	.31	.38	.27	.35	.28
MESH SIZE	4.5"	4.5"	5.5"	5.5"	5.5"
	Annual Distribution Proportions				
3B	.31	.33	.30	.31	.19
3A	.38	.42	.36	.36	.39
2C	.18	.16	.19	.19	.21
2B	.13	.09	.15	.14	.21

An alternative hypothesis to the assumption that fishing effort is equal among PMFC areas is that the area-specific estimates of Z represent valid differences in fishing mortalities among these areas. To examine this, another experiment on annual redistribution was run using mean recruitment from cohort analysis, the 5.5-inch mesh selectivity, and ogive utilization and discarding, and area-specfic estimates of F. Results from this run (Table 10) reduced the annual proportion of fish in Area 3B by 30 percent. These results suggest that the majority of the population annually resides in Area 3A.

Yield Per Million Recruits from the Simulation Model

Population parameter values were selected for these simulations with the following goals in mind: to analyze the effects of different ages at recruitment to the fishing grounds (tp); to compare knife-edge with ogive selectivity; and to provide a final model validation by comparing these with two previously published yield-per-recruit models. Four values of M were decided upon for these simulations: M = 0.28 and 0.35, the most likely values from validation analysis; and M = .14 and 0.21 which coincide with values used in Ehrhardt's and Lenarz's models, respectively. The yields were then summed over age (year classes) and plotted. Parameter values for these simulations were

recruitment = 1,000,000. (250,000 per PMFC Area)

t(p) = age 1 or 4

growth = average annual length- and weight-at-age (Table 8)

redistribution proportions = (Table 10 final cohort column)

selectivity = 5.5-inch ogive or

SKNIFE = 33.29 cm. (length of 50 percent selectivity) utilization and discard equations 3 and 5 or

UKNIFE = 27.22 cm. (length of 50 percent utilization)

M = .14, .21, .28, .35

F = 0.05 to 2.00

a = 1.0 (assumes all discards die)

The results from experiments comparing knife-edge and ogive fishing and discard mortality, and age-at-recruitment to the fishing grounds are illustrated by four sets of yield curves (Figures 28 through 31). Comparison of the knife-edge (Figures 28 and 29) with the ogive fishing mortalities (Figures 30 and 31) illustrates a noticeable difference in the shape of the curves. The knife-edge curves show that yield continues to increase with F, while the ogive curves suggest optimum F ranges from 0.6 to 2.0. These results suggest that a model with knife-edge selectivity would overestimate optimum F. Adding ages one through three to the model reduced optimum F from 1.70 and +5.00 to 1.23 and 1.68 for M = .28 and .35 respectively. These M values were the most likely values from the validation and coincide with recruitment estimates from cohort- and survey-based analyses respectively.

Yield-per-million-recruit curves from this model for M values of 0.14 and 0.21 (Figure 28) are slightly flatter and the yields are a little higher than Ehrhardt's corresponding curves for M values of 0.15 and 0.20 (Figure 6). Ehrhardt's curves for M of 0.15 and 0.20 predict yield-per-million-recruits of approximately 250 t and 200 t respectively while yield-per-million-recruits from this study were 300 t and 250 t for M of 0.14 and 0.21.

Figure 28. Yield per million recruits and fishing mortality rate for four values of M; tp = 4; tp' = knife-edge (selectivity = 5.5 and utilization = 3.6).

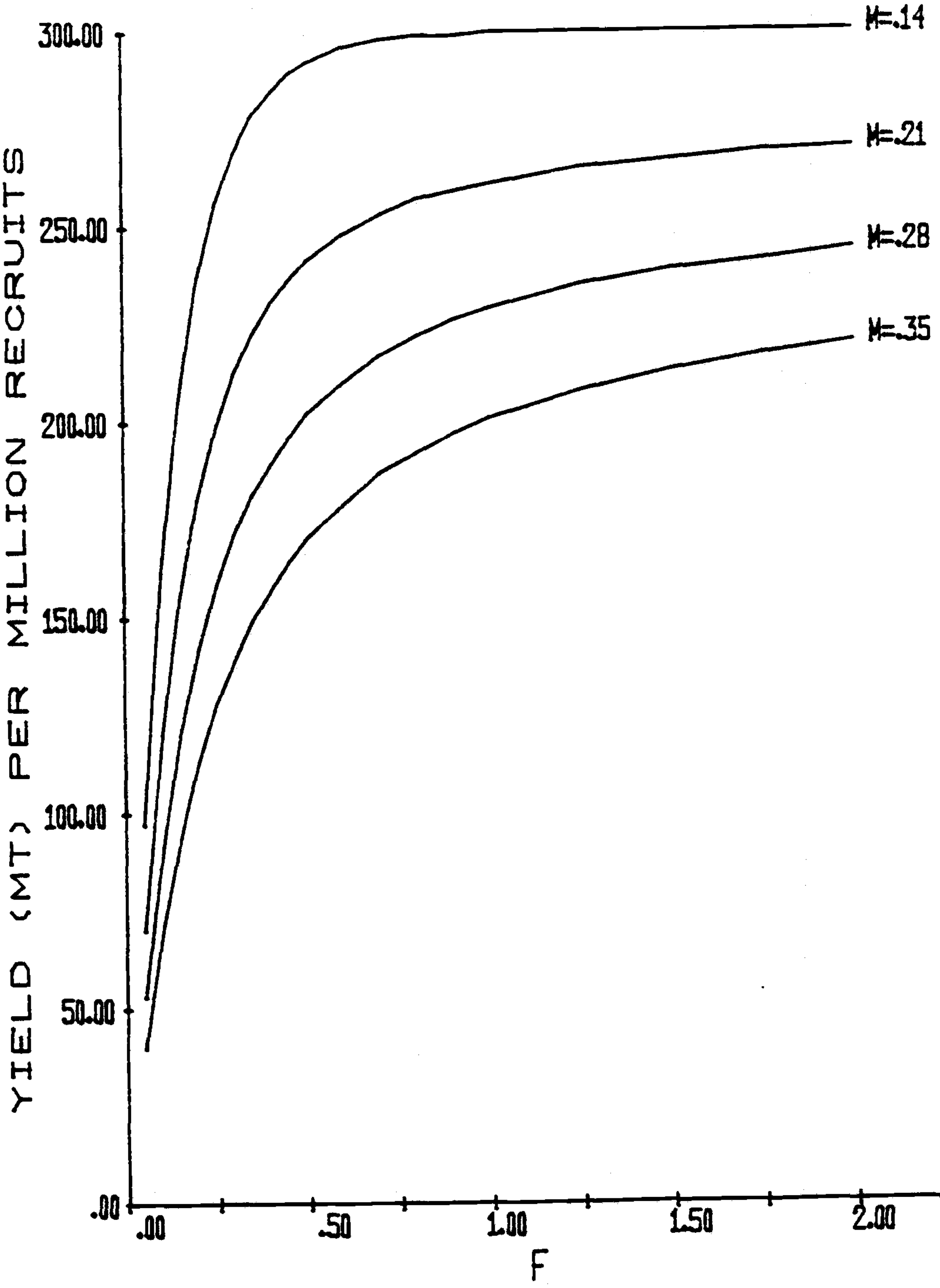


Figure 29. Yield per million recruits and fishing mortality rate for four values of M; tp = 1; tp' = knife-edge (selectivity = 5.5 and utilization = 3.6).

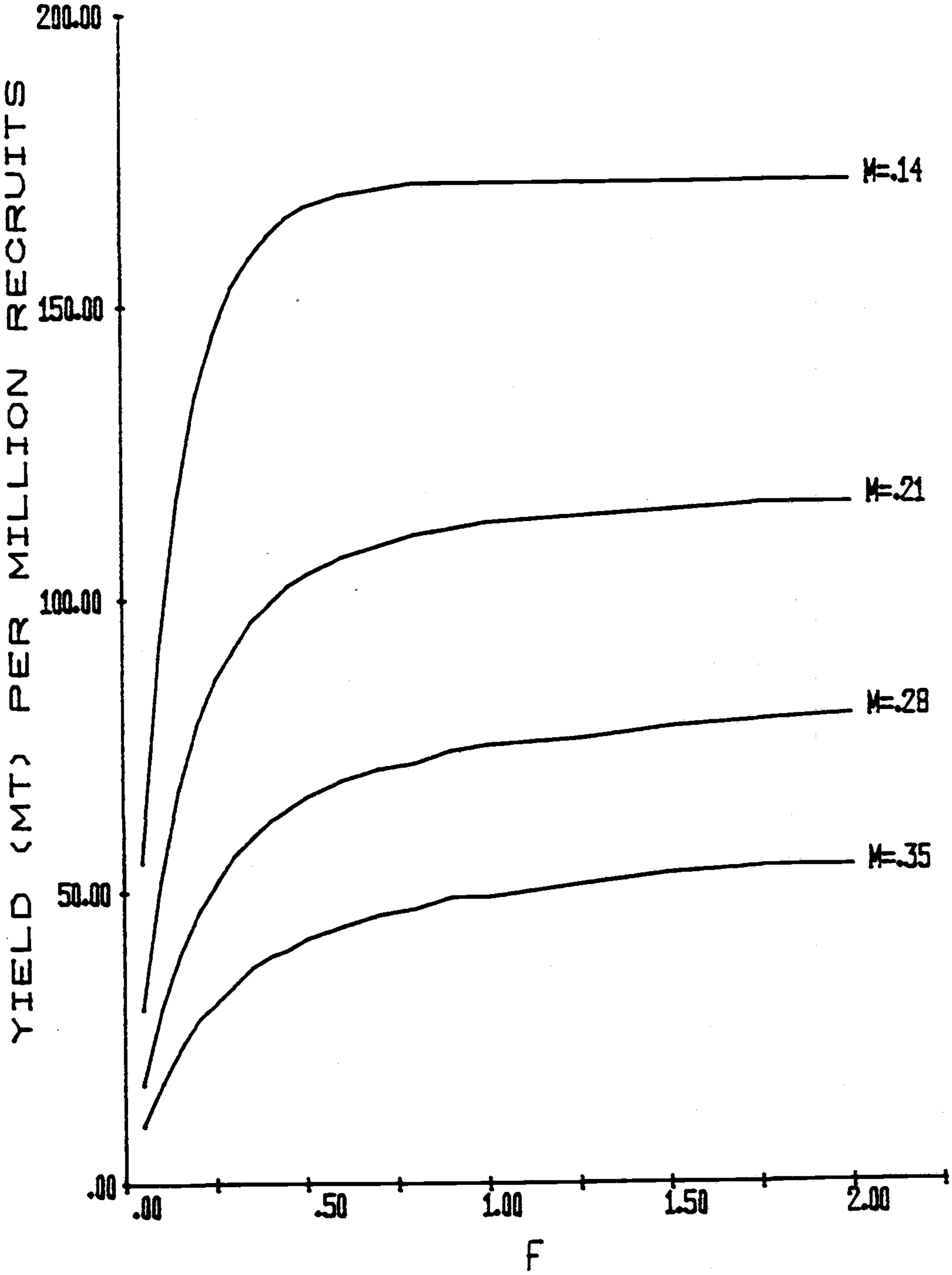


Figure 30. Yield per million recruits and fishing mortality rate for four values of M; tp = 4; tp' = ogive selectivity, utilization and discard rates.

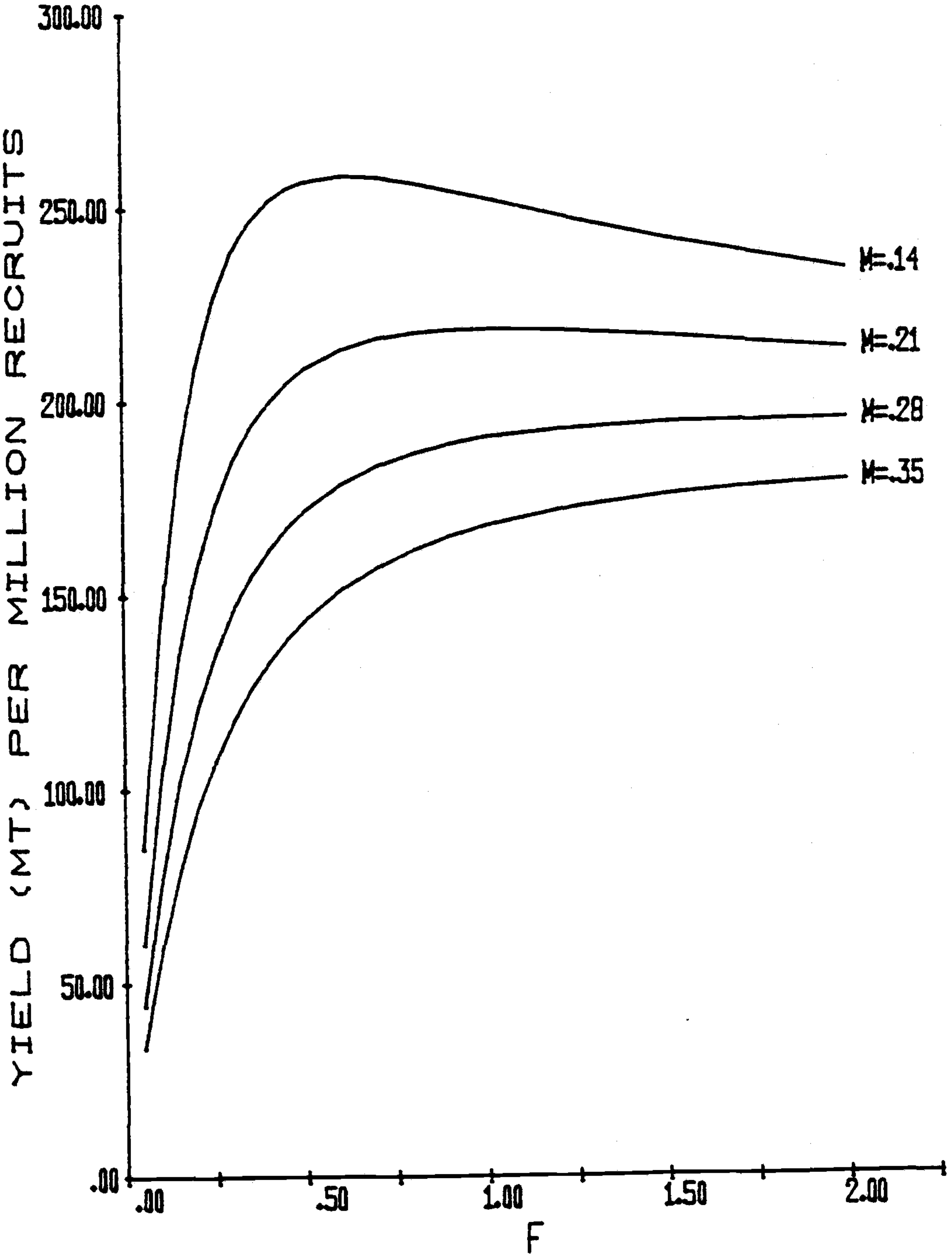
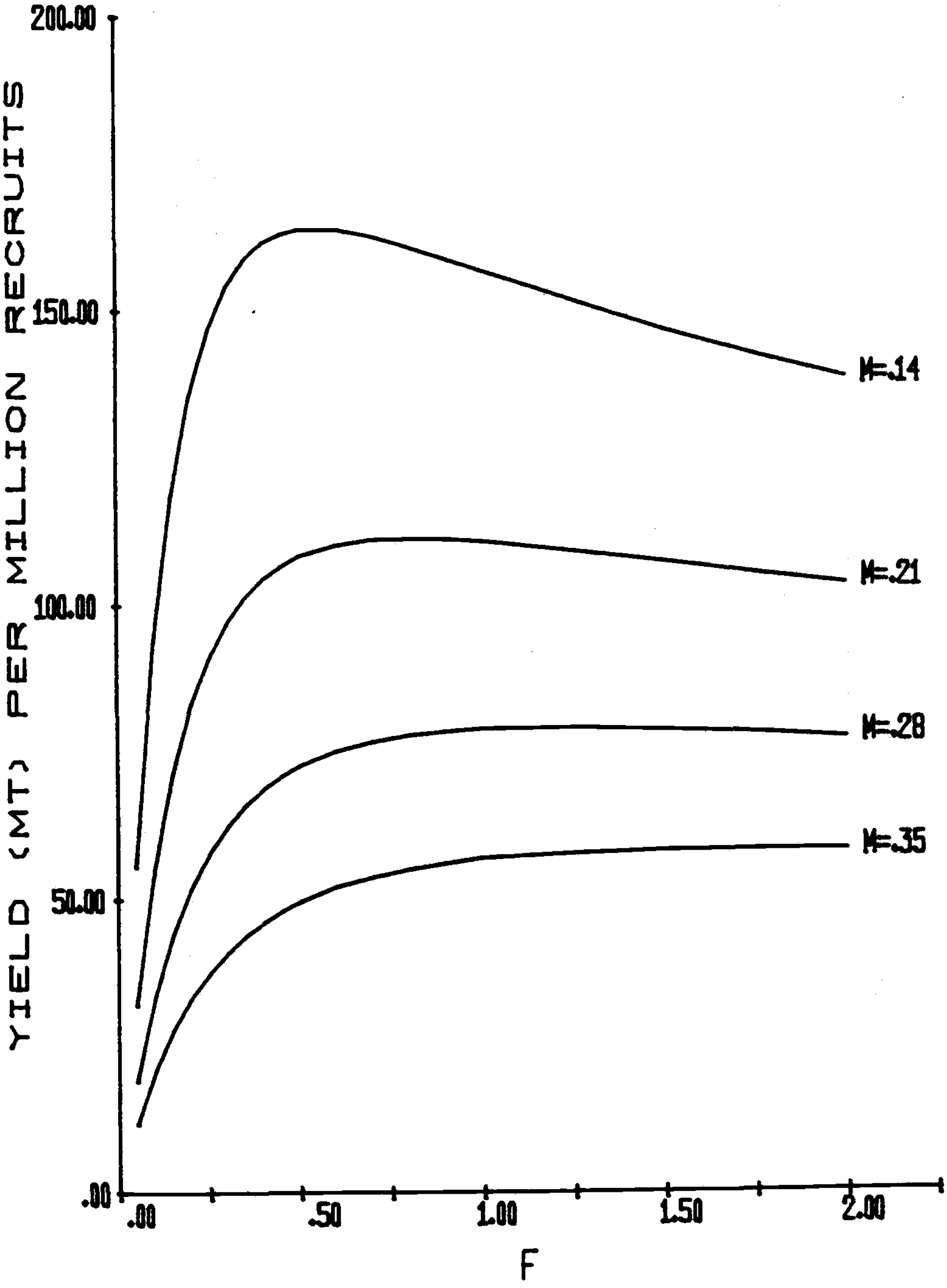


Figure 31. Yield per million recruits and fishing mortality rate for four values of M; tp = 1; tp' = ogive selectivity, utilization and discard rates.



These differences are due to the increased natural mortality Ehrhardt's fish experience for 0.4 years while on the grounds but not fully recruited to the fishery. Some of the difference is also explained by Ehrhardt's use of knife-edge selectivity as illustrated by comparison of Figures 30 and 31. Lenarz Y/R curves with M = .14 and .7, (Figure 27) illustrate steeper descending portions than do comparable curves from the present study (Figure 30). These differences are explained by the different ages-at-recruitment (tp), selectivity and growth in the two models. Lenarz recruits fish to his model at age three compared to age four illustrated in Figure 30. This causes a small increase in the steepness of his Y/R curves as illustrated by comparing Figures 30 and 31. Age at 50 percent selection in the Lenarz study was 3.9 years, while in this model it is 5.4 years. This effectively increases mortality for ages 3.9 to 5.4 in his model and as illustrated by Beverton and Holt in Figure 17.18.2 (1957, p.321) would cause his curves to have steeper descent. Lenarz's Von Bertalanffy Brody constant (k=.14) as opposed to Kreuz's estimate of (k=.266) would also cause his curves to have steeper descent (Figure 17.22, Beverton and Holt 1957, p. 323).

Estimates of MSY

To estimate MSY the simulation model ENGLSH was run with population parameter values the same as in Y/R simulations except for tp and numbers of recruits. Yields were calculated by summing cohorts in a year, rather than summing a cohort over years. Mean recruitment from cohort analysis and survey data (Table 7) were used, and tp set at age four. Age at recruitment to the fishing grounds (tp) was limited to age-four fish as estimates of population numbers and or natural mortality rates for younger fish were unavailable.

The results from the two recruitment levels (Figures 32 and 33) suggest that the fishery was operating below MSY for years 1969 to 1979 at either recruitment level, when catch ranged from 808 t to 2402 t. These results also indicate that MSY for mean recruitment from cohort analysis at M=0.28 is 1854 t at F=1.8 and for survey-based recruitment at M=0.35, MSY=2500 t at F=5.0+. The cohort analysis values (M=0.28, F=1.80, and MSY=1854 t) are the preferred values as suggested by validation results.

Effects of Varying Growth and Recruitment

One of the goals of this study was to measure the effects of varying growth and recruitment rates on yield from the English sole population off Oregon and Washington. To measure these effects this goal was broken down into two parts. Part 1 compared the effects of "simulated" varying growth and recruitment. Part 2 compared the effects of sustained observed extremes in growth and recruitment. These extremes are the actual maximum and minimum deviations in cohort estimates of recruitment (Kruse 1984) and growth (Kreuz et. al. 1982).

The coefficent of variation (C.V.) was selected to compare variations in growth and recruitment. This is commonly used to describe variation in a population (Snedecor and Cochran 1978). It is well suited for this experiment as it accommodates comparison of effects resulting from variables measured in different units.

Figure 32. Yield curves and fishing mortality rates for four values of M; tp = 4; tp' = ogive selection, utilization and discard; mean recruitment estimated from cohort analysis.

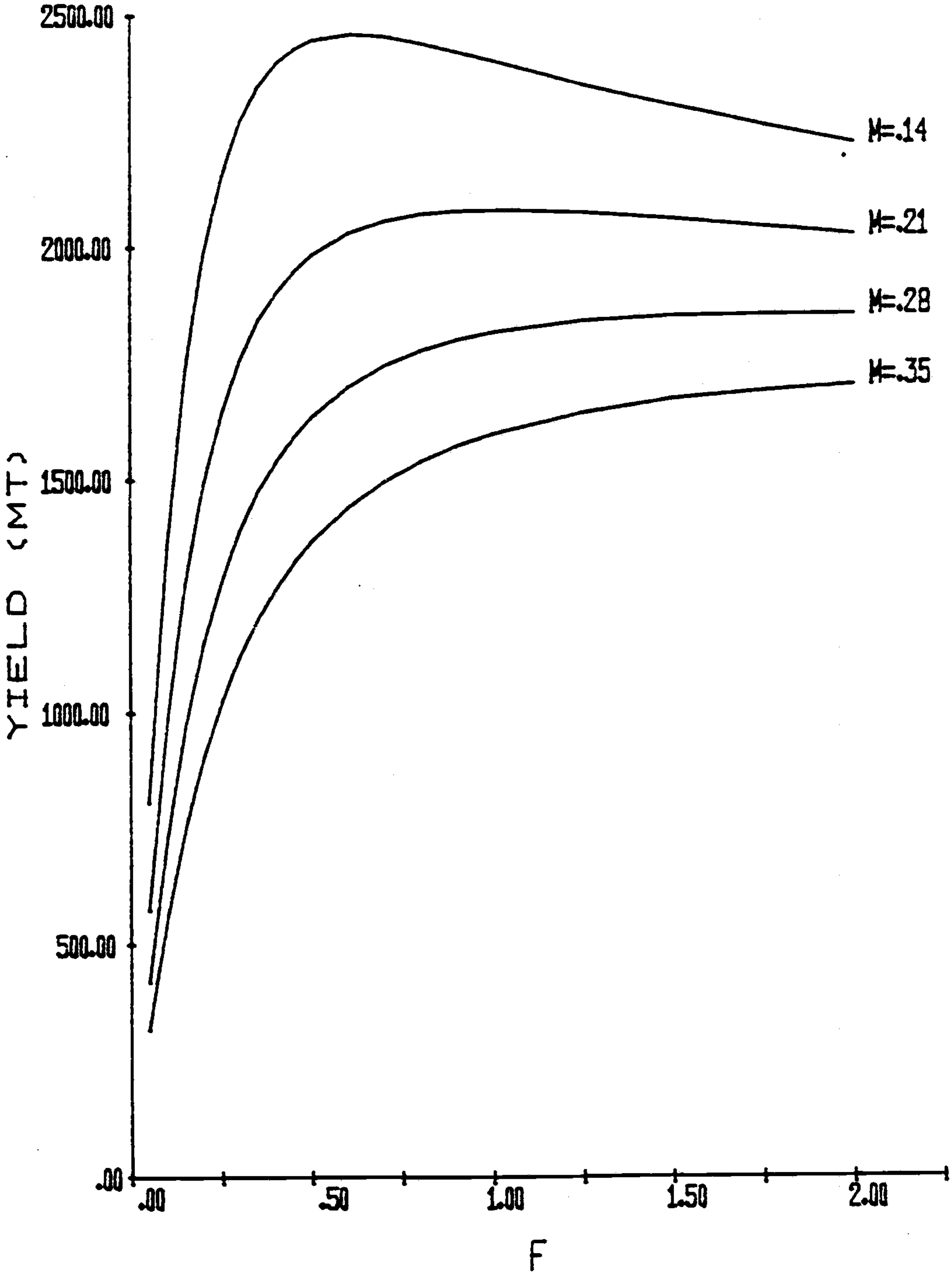
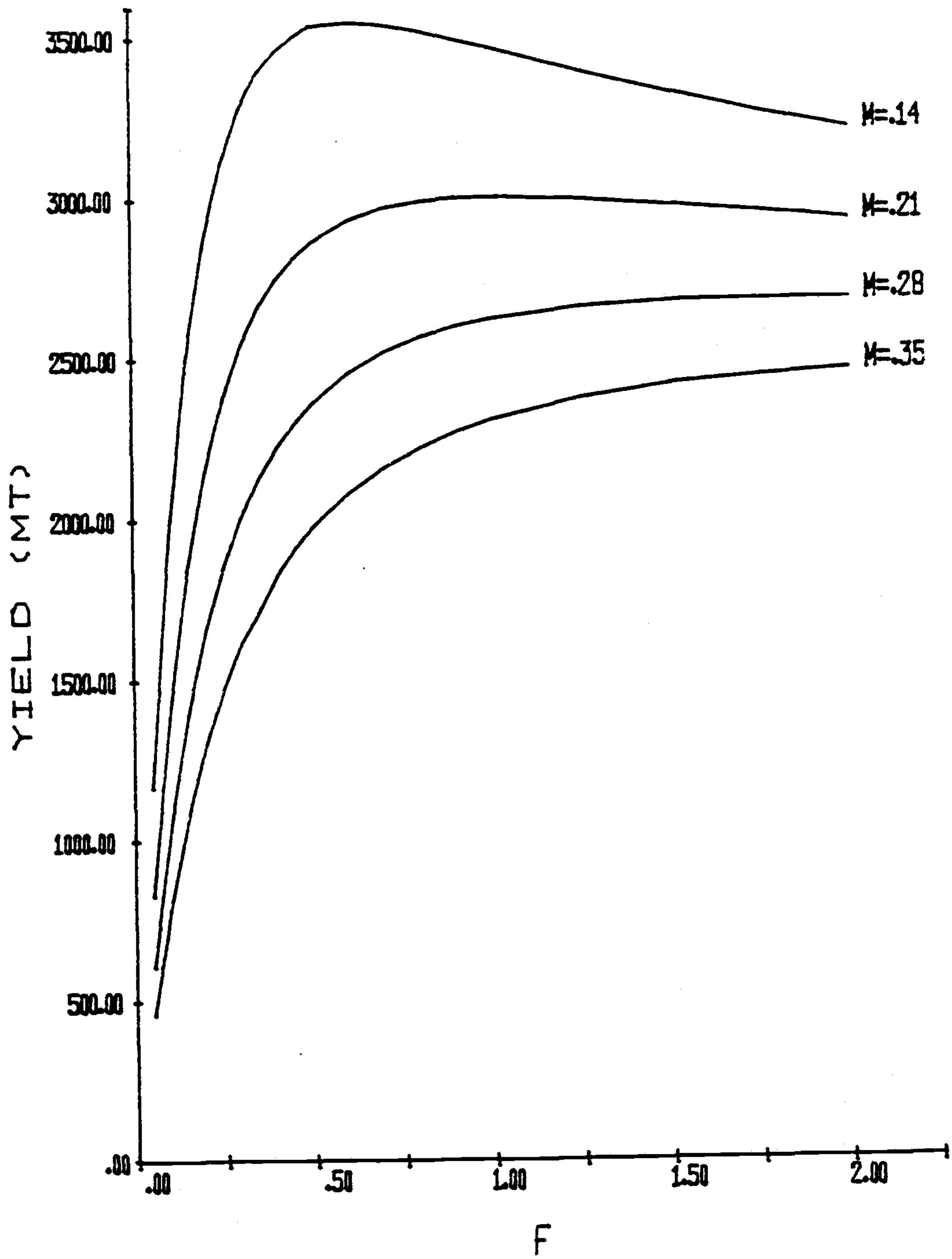


Figure 33. Yield curves and fishing mortality rates for four values of M; tp = 4; tp' = ogive selection, utilization and discards; mean recruitment estimated from Oregon Department of Fish and Wildlife groundfish surveys.



The experiments of Part 1 involved the simulation model ENGLSH run for ten years with population parameters used in "Estimates of MSY" to establish initial populations and age distribution. After that, either varying growth or recruitment was switched on and run for a 60-year period so that the second 30-year period could be examined with all cohorts free of the effects of the initial mean annual growth or recruitment. When growth varied, recruitment was held at the mean level for the period examined, and vice versa. A time series of the driving variables, growth and recruitment, and yields were saved from these runs. Statistics were also calculated for the years 1951 to 1980.

The results from these simulations (Figures 34 and 35) illustrate that varying growth had approximately twice the effect on yield of varying recruitment. This was true even though varying recruitment had almost double the coefficient of variation of varying growth (Figures 34 and 35). It is also important to mention that extreme or outlier recruitment was not considered in this simulation run. Yield responses to varying growth are more abrupt (Figure 34) while those from varying recruitment (Figure 35) appear smoothed. The continued decline of average growth for the years 1950 through 1959 produced (Figure 34) the largest deviation in yield observed with either varying growth or recruitment operating (Figures 34 and 35). Also noticeable is the increase in yield one year after two consecutive positive growth deviations (1958 and 1959). The continued downward trend in recruitment for years 1958 through 1960 produced a moderate dip in yield which began and ended two to three years after the recruitment trend changed.

Figure 34. Time series of potential maximum yield and annual growth of age-one female English sole in the Columbia-Vancouver International North Pacific Fisheries Commission areas.

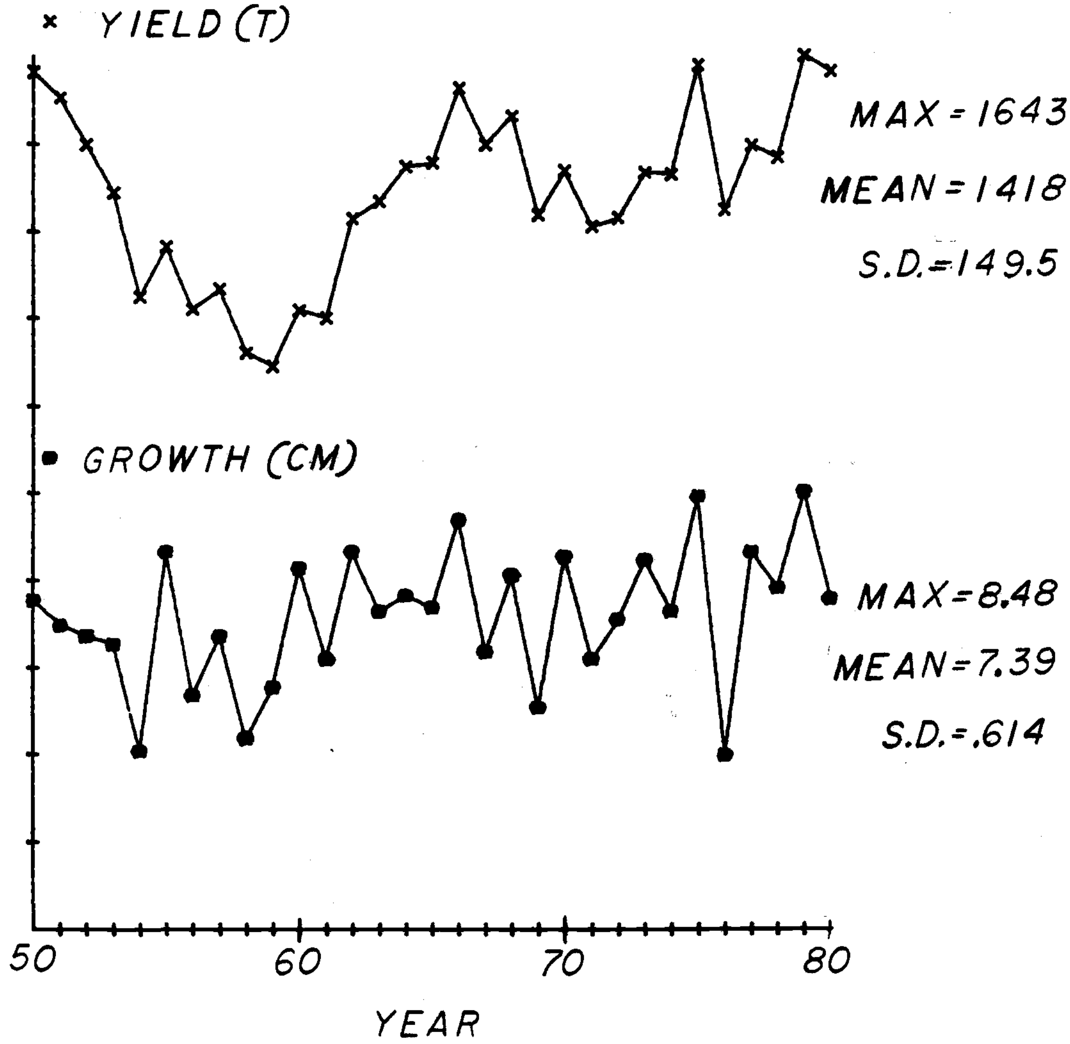
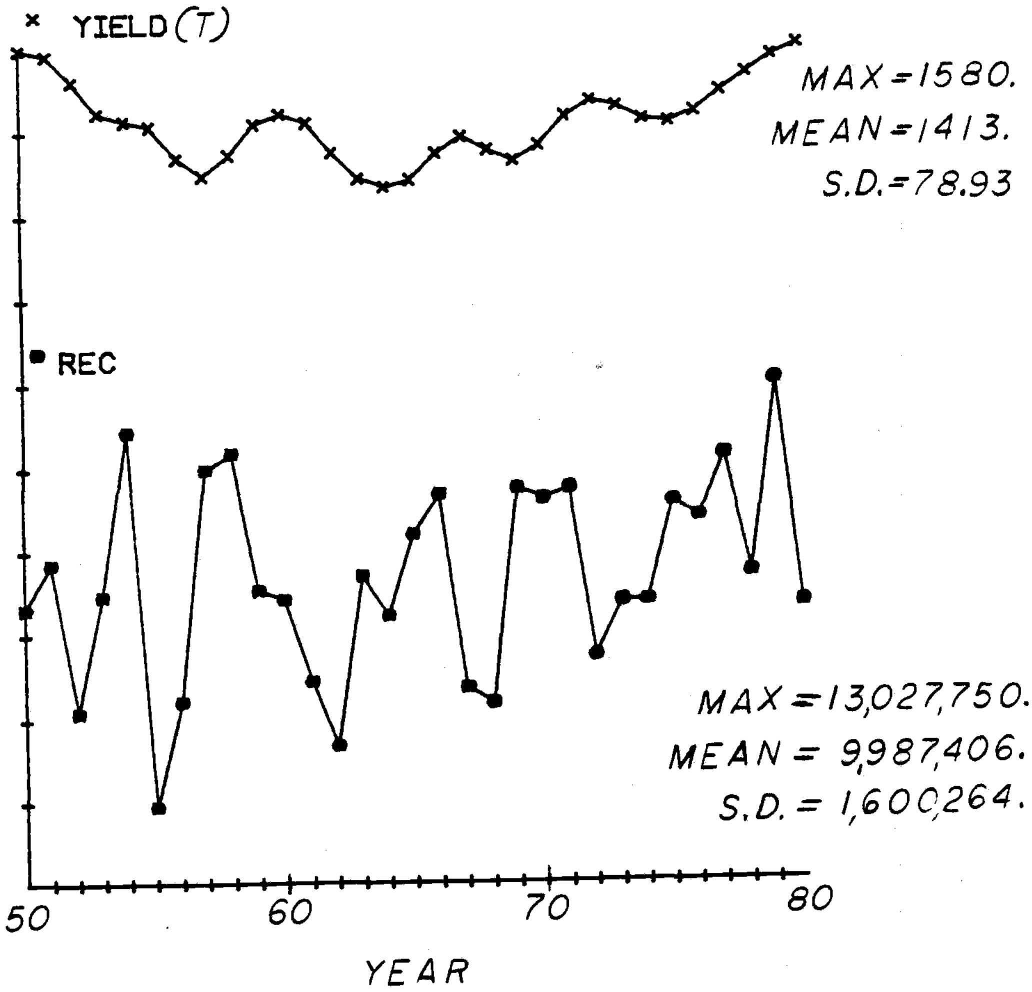


Figure 35. Time series of potential maximum yield and annual recruitment for female English sole in the Columbia-Vancouver International North Pacific Fisheries Commission areas.



Experiments in Part 2 examined the effects of sustained extremes in growth and recruitment. Simulations to examine this consisted of a control with mean growth and recruitment and other population parameter values used in the "Estimates of MSY" and four other simulations with either maximum or minimum growth or recruitment. While growth was maximum or minimum, recruitment was mean, and vice versa. The maximum and minimum values along with means are listed in Table 11. These simulations were run using the same methods and plotting procedures as Estimates of MSY. The yield curve for M = 0.28 and mean recruitment estimates from cohort analysis provided the control.

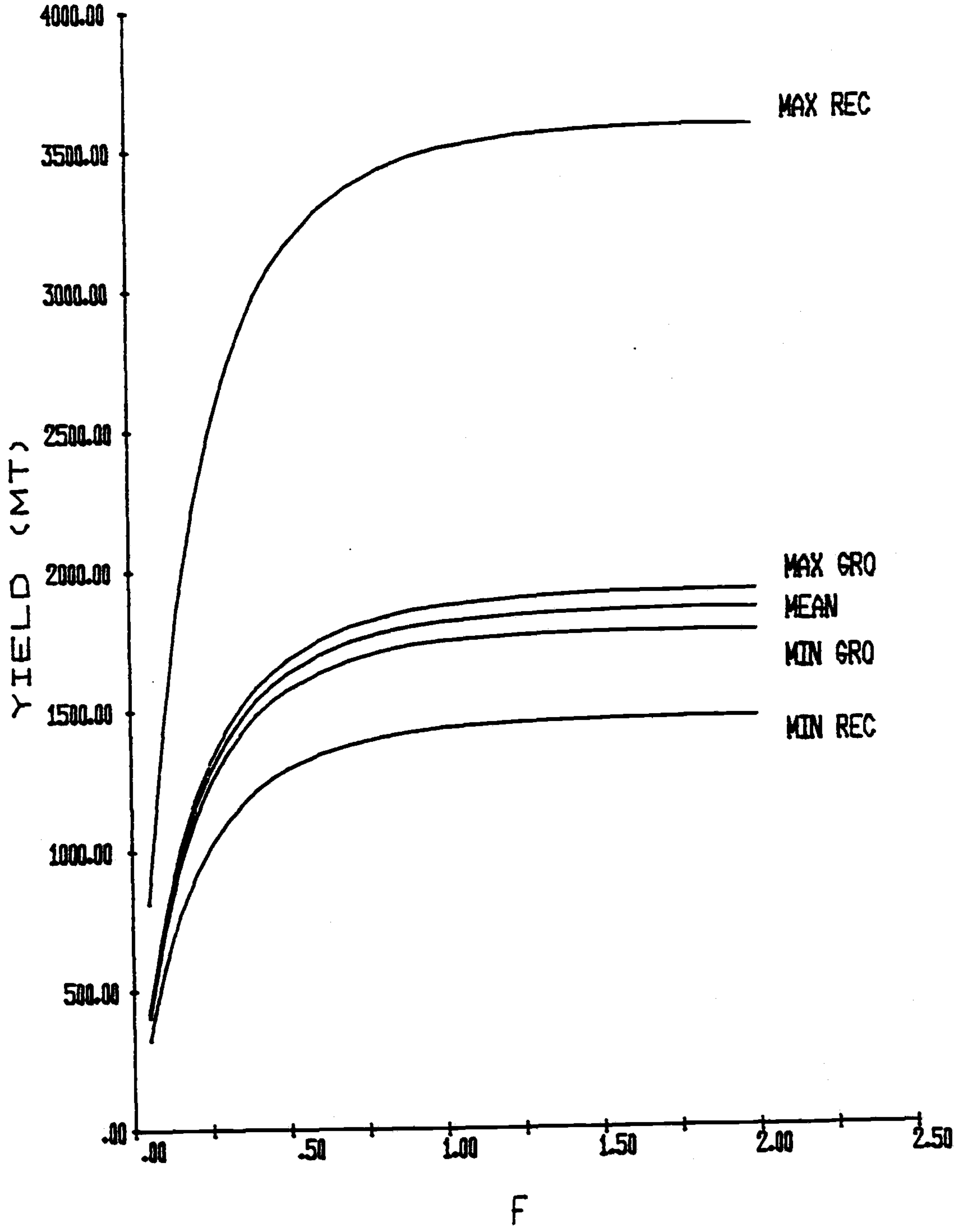
The results from these simulations (Figure 36) illustrate that either maximum or minimum extremes in recruitment, if allowed to continue for the simulated population's life cycle (ten years), would produce considerably larger effects in yields than persistent extreme deviations in growth. Persistent maximum and minimum deviations in growth produced approximately 75 t deviation in yield, while persistent deviations in recruitment produced over 1000 t deviation in yield.

Table 11. Predicted mean and observed maximum and minimum deviations in growth for age-one and numbers of age-four (recruits) female English sole in the Columbia-Vancouver International North Pacific Fisheries Commission Areas.

GROWTH (CM)			
PMFC AREA	-17% DEVIATION'*'	AVERAGE	+13% DEVIATION'*'
3B	4.42	5.32	6.01
3A	3.97	4.78	5.40
2C	4.56	5.50	6.21
2B	4.61	5.56	6.28
RECRUITMENT (thousands)			
PMFC AREA	**MINIMUM'@'**	**AVERAGE'+'**	**MAXIMUM'@'**
3B	1706	2278	4164
3A	2345	3102	5724
2C	1788	2286	4364
2B	1698	1858	4145

@ Kruse (1983) updated Haymans cohort anayalsis.
* Kreuz et al. (1982).
\+ from Table 7. this study.

Figure 36. Yield curves and fishing mortality rates for five sets of growth and recruitment rates; M = 0.28; mean recruitment estimated from cohort analysis; tp = 4; tp' = ogive selectivity, utilization and discard rates.



DISCUSSION

The primary objectives of this study were to determine effects on yield of annual variations in growth and recruitment, age specific fishing and discard mortality and migration rates, and estimate optimal yield for the Columbia-Vancouver management unit.

Model Cost

ENGLSH was written in Fortran V for the CDC Cyber 70 model 73. The code is appended to this thesis. As indicated earlier, the model operates on annual time resolution and maintains records of environmental, population and fishery variables for monitoring or alteration during simulations. Running the model for a sum of approximately 350 years, the time necessary to produce yield data for yield curves, cost approximately 33 SRU-S or $3.50 on prime shift at the Oregon State University Computer Center.

Model Validation

The acceptable region of yields from the response surface analysis of mortality rates for cohort estimates of recruitment is associated with the range of mortality rates that were empirically estimated (Figure 26); however the location of this surface for survey estimates of recruitment (Figure 25) suggest these estimates are high. ODF&W assumed that survey trawl catchability was 1.0. Adjusting this by a small amount would bring their estimates more in line with mortality estimates.

The 5.5-inch cotton mesh ogive reproduced catch-age compositions with slight underestimates of age-two fish. This deviation may be explained by the small numbers of this age fish sampled and the possilility of continued dockside and processor discards prior to sampling. The actual fleet mesh size is probably smaller than 5.5-inch mesh as 50 percent retention lengths for 5.5-inch mesh from recent studies for new synthetic trawl materials is over 38 cm versus the 33.6 cm from Best's cotton gear (Table 6). This difference and the interactive effect of the catch utilization factor emphasize the importance of conducting both gear savings and updating catch utilization studies over the entire Columbia-Vancouver management area.

Results from dispersion or migration validation (Table 9), placing the majority of the fish in the Areas 3B and 3A, confirm Golden's general migration model, northward movement and residence during the majority of the year with return south for two to three months. This type of migration emphasize the importance of quantifying these movements as well as monitoring fishery and population biology parameters along the coast. This is justified by the possibility of intense fishing or an outlier biological event in one of the PMFC areas producing extreme effects on the population and fishery in the other areas.

Age-Specific Fishing and Discard Mortality

The results of comparing knife-edge with ogive selectivity suggest that a model with knife-edge fishery selection would overestimate both optimum F and Yield-per-Recruit or MSY. As in the case of this fishery, 50 percent fleet selectivity length is greater than 50 percent catch utilization length and, as a result, no discards exist. (Figure 22.).

Age at Recruitment to the Fishing Grounds (tp)

Results from examination of tp = 1 versus tp = 4 emphasize the need for natural mortality estimates for ages 1 to 3. The inclusion of discard mortality for ages 1 to 3 reduces optimum F by at least 0.5; however its effect on yield is unquantifiable until estimates of M for ages 1 to 3 are made.

MSY or Optimal Yield

MSY estimates of 1850 to 2500 t are high when considering that both were made excluding discard mortality of ages 1 to 3 and the latter was derived using high mean recruitment estimates from groundfish surveys. This suggests that 1850 t is above the high end of a range of optimal yields for the Columbia-Vancouver Management Area, and serious effort should be made not exceed this yield.

Variations in Growth and Recruitment Rates

Varying growth produced approximately twice the deviation in yield as varying recruitment. This is explained by the fact that variations in growth were synchronous over all year classes at year (t) while recruitment only affected one year class at year (t). In other words, variation in growth affected all cohorts in a given year while varying recruitment affected only the recruited cohort.

Trends in simulated deviations in growth and recruitment produced the most significant affects in yields. Continued positive or negative deviations in growth or recruitment produce more significant changes in yield than random variations. This suggests that three or more years of consistent negative or positive deviations would produce significant effects on yields from this fishery. This emphasizes the need to initiate research for monitoring and developing further understanding of these events.

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APPENDIX

APPENDIX

Computer program for simulation model 'ENGLSH'.

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C      MODEL ENGLSH1:       A COMPUTER SIMULATION MODEL
C         OF FEMALE ENGLISH SOLE OFF THE OREGON AND
C         WASHINGTON COASTS(PMFC AREAS 2B,2C,3A,3B).
C         MODELED BY T. R. HAYDEN AND PROGRAMED BY ERIC BEALS AND
C         T. R. HAYDEN.
C     RECRUITMENT: ENGLSH AFFORDS A SELECTION OF FOUR RECRUITMENT REGIMES,
C         TWO ESTIMATES OF MEAN RECRUITMENT AND TWO ESTIMATES OF ANNUALLY
C         VARYING RECRUITMENT. RECRUITMENT IS DEFINED AS THE NUMBER OF AGE
C         FOUR FEMALE ENGLSH SOLE ENTERING THE MODEL (FISHERY) ANNUALLY.
C         RECRUITMENT DEFAULTS TO MEAN ANNUAL ESTIMATE BASED PRIMARILY ON
C         COHORT ANALYSIS CONDUCTED BY HAYMAN ET. AL. 1980.
C     GROWTH: ENGLSH OFFERS MEAN ANNUAL OR ANNUALLY VARYING GROWTH.
C         ANNUAL LENGTH AT AGE IS ESTIMATED USING KREUZ'S VON BERTALANFFY
C         GROWTH EQUATION AND MEAN LENGTH IS ESTIMATED USING A LOGISTIC
C         EXPRESSION OF KREUZ'S SEASONAL GROWTH DATA. THE MODEL DEFAULTS
C         TO MEAN ANNUAL GROWTH WITH THE AVERAGE LENGTH EST. USING THE
C         MEAN NO. OF (DAYS) TILL HALF THE COMM. CATCH IS LANDED BY PMFC AREA.
C    FISHING MORTALITY: ENGLSH OFFERS TWO FISHERY MANAGEMENT REGIMES. BOTH
C         UTILIZE AGE SPECIFIC MESH SELECTION (E.A. BEST 61) AND CATCH
C         UTILIZATION (TENEYCK AND DEMORY 75) TO ADJUST INSTANTANEOUS FISHING
C         MORTALITY (F). DEFAULT MANAGEMENT REGIME THE MODELER SELECTS
C         (F) WHILE THE OTHER REGIME THE MODELER SETS A QUOTA AND THE MODEL
C         SELECTS (F) TO TAKE THE QUOTA
C    SURVIVAL: NEGATIVE EXPONENTIAL SURVIVAL IS USED WITH AGE SPECIFIC
C         MESH SELECTION AND CATCH UTILIZATION INCORPORATED IN (F) AND
C         THE ADDITION OF DISCARDING MORTALITY (DMORT) TO TOTAL MORTALITY.
C         THE MODEL ALSO AFFORDS A SELECTION OF THAT FRACTION
C         (A) OF THE DISCARDED FISH THAT DIE. DEFAULT (A)=1.0 (ASSUMES ALL
C         DISCARDED FISH DIE). NATURAL MORTALITY (NMORT) MAY BE SET HOWEVER
C         IT DEFALUTS TO NMORT=.2000
C     REDISTRIBUTION: THE MATURE POPULATION MODELED IS REDISTRIBUTED TO
C         PMFC AREAS PROPORTIONAL TO THE COMMERCIAL CATCHS OBSERVED 1960-79.
C         THE IMMATURE POPULATION IS REDISTRIBUTED TO PMFC AREAS IN PROPORTION
C         TO THE NO'S. OBSERVED DURING THE ODF&W GRD. FSH. SURVEYS 1971-76.
C
C-----------------------------------OPERATION INSTRUCTIONS---------------------------
C
C
C      DEFAULT OPERATION OF THE MODEL RESULTS IN ITS OPERATIONS IN THE
C      DYNAMIC POOL MODE WITHONSTANT MEAN RECRUITMENT BASED PRIMARILY
C      UPON COHORT ANALYSIS (HAYMAN ET. AL. 1980),MEAN ANNUAL GROWTH
C      ESTIMATED FROM KIETH KREUZ'S WORK 1978,AND CONSTANT ANNUAL NATURAL
C      MORTALITY (NMORT=0.2) ALSO FROM HAYMAN ET. AL.. THE OPERATOR
C      MUST FIRST RUN THE MODEL FOR 10 YEARS TO ALLOW RECRUITMENT TO
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C      BUILD A POPULATION WITH STABLE AGE DISTRIBUTION. THEN SELECT
C      AREA SPECIFIC FISHING MORTALITY (F3B=0.3,F3A=0.3,F2C=0.3,F2B=0.3),
C      RUN THE MODEL FOR A DESIRED NUMBER OF YEARS AND MONITOR AVAILABLE
C      OUTPUTS. SEE 'DEFINITION OF VARIALBES' FOR AVAILABLE OUTPUT VARIALBES.
C           THIS MODEL AFFORDS THE USER THE FOLLOWING VARIATIONS;
C      I.   RECRUITMENT
C           A.   A CHOICE OF TWO MEAN  ANNUAL RECRUITMENT REGIMES
C                (1.) MEAN RECRUITMENT         (2.) MEAN RECRUITMENT
C                BASED PRIMARILY UPON          BASED PRIMARILY UPON
C                COHORT ANALYSIS               SURVEY ANALYSIS
C                DEFAULT(COHORT=1.0)           (COHORT=0.0)
C                DEFAULT(VARREC=0.0)           (VARREC=0.0)
C           B.   A CHOICE OF TWO ANNUALLY VARYING RECRUITMENT REGIMES
C                (1.) VARYING RECRUITMENT      (2.) VARYING RECRUIMENT
C                BASED PRIMARILY UPON          BASED PRIMARILY UPON
C                COHORT ANALYSIS AND           SURVEY ANALYSIS AND
C                USING THE RECRUITMENT         USING THE RECRUITMENT
C                MODEL DESCRIBED BY HAYMAN     MODEL DESCRIBED BY HAYMAN
C                (VARREC=1.0)                  (VARREC=1.0)
C                DEFAULT(COHORT=1.0)           (COHORT=0.0)
C      II.  GROWTH
C           A.   A CHOICE OF ANNUAL MEAN OR ANNUALLY VARYING GROWTH
C                (1.) MEAN GROWTH              (2.) VARYING GROWTH
C                ESTIMATED USING KREUZ'S       ESTIMATED USING KREUZ'S
C                VON BERTALANFFY AND           GROWTH WITH BOTTOM
C                SEASONAL GROWTH ESPRES        TEMPERATURE AND SEASONAL
C                SIONS                         GROWTH ESPRESSION
C                DEFAULT (VARGRO=0.0)          (VARGRO=1.0)
C      III. FISHING MORTALITY
C           A.   A CHOICE OF MANAGING BY SELECTING (F) OR (YIELD)
C                (1.) MODELER SELECTS          (2.) MODELER SELECTS
C                F                             YIELD
C                DEFAULT(QUOTA=0.0)            (QUOTA=TOTAL YIELD IN METRIC TONNES
C           B.   A CHOICE OF KNIFE EDGE OR LEGISTIC MESH SELECTION
C                (1.) LOGISTIC MESH            (2.) KNIFE EDGE MESH
C                SELECTION (E.A. BEST          SELECTION
C                1971)                         (SKNIFE=50 PERCENT SELECTION
C                DEFAULT (SKNIFE=0.0)          LENGTH IN CM. TOTAL LENGTH)
C           C.   A CHOICE OF KNIFE EDGE OR LOGISTIC CATCH UTILIZATION
C                (1.) LOGISTIC CATCH           (2.) KNIFE EDGE CATCH
C                UTILIZATION TENEYCK           UTILIZATION (UKNIFE=
C                AND DEMORY 1975.              50 PERCENT UTILIZATION
C                DEFAULT(UKNIFE=0.0)           LENGTH
C      IV.  SURVIVAL
C           A. A CHOICE OF NATURAL MORTALITY RATE AND THE PROPORTION OF
C           DISCARDED FISH THAT DIE
C                (1.) MODELER SELECTS          (2.) MODELER SELECTS
C                NATURAL MORTALITY             FRACTION OF DEAD DISCARDS
C                DEFAULT(NMORT=0.2)            DEFAULT(A=1.0) ASSUMES ALL DISCARDS DIE
C      V.   REDISTRIBUTION
C           A.   A CHOICE OF REDISTRIBUTION OR NOT
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C              (1.) REDISTRIBUTION      (2.) REDISTRIBUTION
C              BASED UPON ODF&W SURVEY   OFF
C              RECRUTIMENT ESTIMATES     (REDIST=0.0)
C              AND PROPORTIONS NECESSARY
C              TO SIMULATE THE 1960-79
C               COMMERCIAL CATCH RECORDS
C               DEFAULT(REDIST=1.0)
      SUBROUTINE UMODEL (IT)
      REAL NMORT,LENFLAG,LENMAX,K
      REAL N,N3B,N3A,N2C,N2B
      REAL NHAT3B,NHAT3A,NHAT2C,NHAT2B,NHAT
      REAL IMATR3B,IMATR3A,IMATR2C,IMATR2B
      REAL MATUR3B,MATUR3A,MATUR2C,MATUR2B
      REAL MTRB1,MTRB2,MATURE
      COMMON COHORT,BARO,RDATA(30),B,RECBARC,RECBARS,GROBAR
      COMMON VARGRO,LENFLAG,GYEAR,BTMTEMP,SEALEV,VARREC,GDATA(30),D
      COMMON LENMAX,K,TNOT,BTCON1,BTCON2,BTCON3,VGRCON1,VGRCON2
      COMMON ANLEN3B(14),ANLEN3A(14),ANLEN2C(14),ANLEN2B(14)
      COMMON ANGRO3B(14),ANGRO3A(14),ANGRO2C(14),ANGRO2B(14)
      COMMON REC3B,REC3A,REC2C,REC2B,TREC,COVAREC,RECHAT(12)
      COMMON ANVGR3B(14),ANVGR3A(14),ANVGR2C(14),ANVGR2B(14)
      COMMON DAYS3B,DAYS3A,DAYS2C,DAYS2B,RYEAR,PCT(14),GRSUTCH
      COMMON AVGRO3B(14),AVGRO3A(14),AVGRO2C(14),AVGRO2B(14),GROFLAG
      COMMON AVLEN3B(14),AVLEN3A(14),AVLEN2C(14),AVLEN2B(14)
      COMMON WT3B(14),WT3A(14),WT2C(14),WT2B(14),WTCONN,WTEXPN
      COMMON SEL3B(14),SEL3A(14),SEL2C(14),SEL2B(14),WTCONS,WTEXPS
      COMMON SELB1,SELB2,SKNIFE,VONB,KNIFE
      COMMON UTL3B(14),UTL3A(14),UTL2C(14),UTL2B(14)
      COMMON DSCRD3B(14),DSCRD3A(14),DSCRD2C(14),DSCRD2B(14)
      COMMON UTLB1,UTLB2,UKNIFE
      COMMON DMORT3B(14),DMORT3A(14),DMORT2C(14),DMORT2B(14)
      COMMON F3B,F3A,F2C,F2B,QUOTA
      COMMON FMORT3B(14),FMORT3A(14),FMORT2C(14),FMORT2B(14)
      COMMON CATCH3B(14),CATCH3A(14),CATCH2C(14),CATCH2B(14),NMORT
      COMMON TOTCC3B,TOTCC3A,TOTCC2C,TOTCC2B
      COMMON PCTCP3B(14),PCTCP3A(14),PCTCP2C(14),PCTCP2B(14)
      COMMON YTONS3B(14),YTONS3A(14),YTONS2C(14),YTONS2B(14)
      COMMON YLBS3B(14),YLBS3A(14),YLBS2C(14),YLBS2B(14)
      COMMON YIELD3B,YIELD3A,YIELD2C,YIELD2B,XYTONS
      COMMON EYELD3B,EYELD3A,EYELD2C,EYELD2B
      COMMON TCATCH,TYIELD,TEYELD,A
      COMMON SFPOP3B(14),SFPOP3A(14),SFPOP2C(14),SFPOP2B(14)
      COMMON SPOP3B,SPOP3A,SPOP2C,SPOP2B,SFPOP(14)
      COMMON STONS3B(14),STONS3A(14),STONS2C(14),STONS2B(14)
      COMMON SLBS3B(14),SLBS3A(14),SLBS2C(14),SLBS2B(14)
      COMMON SBIOM3B,SBIOM3A,SBIOM2C,SBIOM2B
      COMMON SEBIM3B,SEBIM3A,SEBIM2C,SEBIM2B
      COMMON TSPOP,TSBIOM,TSEBIOM
      COMMON NHAT3B(14),NHAT3A(14),NHAT2C(14),NHAT2B(14),NHAT(14)
      COMMON N,N3B,N3A,N2C,N2B
      COMMON C,F,C3B,C3A,C2C,C2B
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      COMMON MATUR3B(14),MATUR3A(14),MATUR2C(14),MATUR2B(14)
      COMMON MTRB1,MTRB2
      COMMON IMATR3B(14),IMATR3A(14),IMATR2C(14),IMATR2B(14)
      COMMON DIST3BC,DIST3AC,DIST2CC,DIST2BC
      COMMON DIST3BS,DIST3AS,DIST2CS,DIST2BS
      COMMON RHAT3BC,RHAT3AC,RHAT2CC,RHAT2BC,REDIST,TRHATC
      COMMON RHAT3BS,RHAT3AS,RHAT2CS,RHAT2BS,TRHATS
      COMMON RFPOP3B(14),RFPOP3A(14),RFPOP2C(14),RFPOP2B(14)
      COMMON RFPOP(14),RPOP3B,RPOP3A,RPOP2C,RPOP2B
      COMMON RTONS3B(14),RTONS3A(14),RTONS2C(14),RTONS2B(14)
      COMMON RLBS3B(14),RLBS3A(14),RLBS2C(14),RLBS2B(14)
      COMMON RBIOM3B,RBIOM3A,RBIOM2C,RBIOM2B
      COMMON REBIM3B,REBIM3A,REBIM2C,REBIM2B
      COMMON TRPOP,TRBIOM,TREBIOM
C
C-------TABLE FINC (FISHING MORTALITY INCREMENTS) USED WHEN QUOTA OPERATIONAL.
C
      DIMENSION FINC(9)
      DATA FINC /1.28, .64, .32, .16, .08, .04, .02, .01, .01/
C
C--------------DEFINITION OF VARIABLES USED IN THIS MODEL------------
C
C     A             FRACTION OF DISCARDED FISH THAT DIE
C     ANGRO(  )(I)  AREA AND AGE SPECIFIC ANNUAL GROWTH IN LENGTH
C     ANLEN(  )(I)  AREA AND AGE SPECIFIC AVERAGE ANNUAL LENGTH
C     ANVGR(  )(I)  AREA AND AGE SPECIFIC ANNUAL GROWTH INCLUDING ANNUAL VARIATION
C     AVGRO(  )(I)  AREA AGE AND TIME SPECIFIC ANNUAL GROWTH
C     AVLEN(  )(I)  AREA AGE AND TIME SPECIFIC ANNUAL LENGTH
C     B             MULTIPLIER FOR COEFFICIENT OF VARIATION USED TO EXAMINE
C     BTCON1        CONSTANT IN THE BOTTOM TEMPERATURE FUNCTION. Y INTERCEPT.
C     BTCON2        CONSTANT IN THE BOTTOM TEMPERATURE FUNCTION, SLOPE.
C     BTCON3        CONSTANT IN THE BOTTOM TEMPERATURE FUNCTION, METRIC CONVERSION
C                   RELATIVE VARIABILITY IN RECRUITMENT
C     GROBAR        MEAN GROWTH FOR AGE 2 AREA 3A ESTIMATED FROM K. KREUZ'S
C                   MODEL OF ANNUALLY VARYING GROWTH USING 30 YEARS DATA 1951-80
C     BARO          THE SUM OF SEPT. AND OCT. MONTHLY MEAN BAROMETRIC PRESSURE AT
C                   46 DEGRESS N. L. 124 DEG.W.L. IN MILLIBARS*10-10000
C     BTMTEMP       JUNE BOTTOM TEMP IN DEG. C AT NH-15 OFF NEWPORT ORE.
C     C             TOTAL CATCH FROM MODELED POP FOR AGES GREATER THAN 5
C     C(  )         AREA SPECIFIC CATCHS FOR AGES GREATER THAN 5 YRS.
C     CATCH(  )(I)  AREA AND AGE SPECIFIC AT SEA CATCH
C     COHORT        A SWITCH TO SELECT COHORT OR SURVEY ESTIMATES OF RECRUITMENT
C     COVAREC       A SWITHC TO SELECT PREDICTED OR OBSERVED COHORT EST OF REC.
C     D             MULTIPLIER FOR COEFFICIENT OF VARIATION USED TO EXAMINE
C                   RELATIVE VARIABILITY IN GROWTH
C     DAYS(  )      AREA SPECIFIC NUMBER OF DAYS TILL HALF THE ANNUAL CATCH IS LANDED
C     DIST(  )C     AREA SPECIFIC PROPORTION OF FISH DISTRIBUTED TO PMFC AREAS
C                   FOR COHORT BASED ESTIMATES OF RECRUITMENT
C     DIST(  )C     AREA SPECIFIC PROPORTION OF FISH DISTRIBUTED TO PMFC AREAS
C                   FOR SURVEY BASED ESTIMATES OF RECRUITMENT
C     DSCRD(  )(I)  AREA AND AGE SPECIFIC PROPORTION OF CATCH DISCARDED
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C      EYELD(  )     AREA SPECIFIC LANDINGS IN LBS.
C      FINC          AN ARRAY OF INTERVAL HALVINGS TO ESTIMATE F WHEN QUOTA OPERATIONAL
C      F            INSTANTANEOUS FISHING MORTALITY FOR POP MODELED ESTIMATED FROM
C                    ITERATIVE SOLUTION OF BARANOV CATCH EQUATION USING CATCH AND
C                    POPULATION OF AGE 6 AND GREATER AND GIVEN NATURAL MORTALITY
C      F(  )         AREA SPECIFIC INSTANTANEOUS FISHING MORTALITY
C      FMORT(  )(I)  AREA AND AGE SPECIFIC INSTANTANEOUS FISHING MORTALITY
C                    ADJUSTED BY MESH SELECTION AND CATCH UTILIZATION.
C      GDATA         30 YEAR ARRAY OF SEALEVEL DATA RECORDED OFF NEAH BAY WASH.
C      GROFLAG       FLAG TO TURN OFF INITIAL EST. OF ANNUAL GROWTH AT AGE
C      K             VON BERTALANFFY GROWTH COEFFICIENT
C      GYEAR         ANNUAL INDEX OF SEALEVEL DATA
C      IMATR(  )(  ) AREA AND AGE SPECIFIC PERCENT IMMATURE
C      LENFLAG       FLAG TO TURN OFF VONBERT ESTIMATE OF INITIAL LENGTH AT AGE
C      MATUR(  )(  ) AREA AND AGE SPECIFIC PERCENT MATURE FROM HARRY 59.
C      MTRB1         PARAMETER FOR PERCENT MATURITY WHICH CONTROLS LATERAL PLACEMENT
C      MTRB2         PARAMETER FOR PERCENT MATURITY WHICH CONTROLS RATE OF CHANGE
C      LENMAX        VON BERTALANFFY ASYMPTOTIC LENGTH
C      N            TOTAL POP OF AGE 6 AND GREATER USED IN ITERATIVE EST. OF F
C      N(  )         AREA SPECIFIC POP OF AGE 6 AND GREATER USED TO EST. N(ABOVE)
C      NHAT(  )(  )  AREA AND AGE SPECIFIC GROUND FISH POP ESTIMATES O.D.FSW.
C      NHAT(  )      GRD. FISH POP. EST. BY AGE ALL FOUR PMFC AREAS COMBINE
C      NMORT         INSTANTANEOUS NATURAL MORTALITY RATE
C      PCT(  )       PROPORTION OF AGE 2 ANNUAL GROWTH OBSERVED AT SUCESSIVE (AGES)
C      PCTCP(  )(I)  AREA SPECIFIC PERCENTAGE AGE COMPOSITION OF COMM. LANDINGS
C      QUOTA         TOTAL YIELD (M.T) FOR ALL AREAS MODELED AND A SWITCH FOR QUOTA MANAGEMENT STRATEGY
C                    DEFAULT QUOTA=0.0 AND MODELER SETS FISHING MORTALITY, ALTERNATIVE MODELER SETS
C                    QUOTA = DESIRED YIELD IN METRIC TONNES FOR ALL FOUR PMFC AREAS
C      RBIOM         TOTAL TONNES IN REDISTRIBUTED POPULATION
C      RBIOM(  )     AREA SPECIFIC REDISTRIBUTED POPULATION IN TONNES
C      RDATA         30 YEAR ARRAY OF BAROMETRIC PRESSURE DATA FROM 46 124
C                    ( 15 NAUTICAL MILES SOUTH SOUTH WEST OF MOUTH OF COLUMBIA R.)
C      REBIM(  )     AREA SPECIFIC POPULATION AFTER REDISTRIBUTION IN LBS.
C      REC(  )       AREA SPECIFIC NUMBER OF AGE 4 FEMALES ENTERING MODEL
C      RECBARC       MEAN ANNUAL  RECRUITMENT FOR AREA 3A ESITMATED FROM HAYMAN'S
C                    RECRUITMENT MODEL FOR YEARS 1951-80
C      RECBARS       MEAN ANNUAL  RECRUITMENT FOR AREA 3A ESITMATED FROM HAYMAN'S
C                    RECRUITMENT MODEL FOR YEARS 1951-80 ADJUSTED TO GRD. FHS. SURVEY
C                    ESTIMATES 1971-76
C      RECHAT        AN ARRAY OF HAYMANS COHORT ESTIMATES OF NOS. OF AGE 4
C                    FEMALE ENGLISH SOLE IN AREA 3A FOR YEARS 1959-70.
C      REDIST        A SWITCH TO SELECT AREA AND AGE SPECIFIC POPULATION REDISTRIBUTION
C                    PROPORTIONAL TO POP. EST. FROM ODFIW GRD. FSH. SUR. 1971-76.
C                    DEFAULT IS REDISTRIBUTION ON (REDIST = 1.0)
C      RFPOP(I)      AGE SPECIFIC NUMBERS OF FEMALE ENG. SOLE AFTER REDISTRIBUTION
C      RFPOP(  )(I)  AREA AND AGE SPECIFIC NUMBERS OF FEMALE FISH AFTER REDISTRIBUTION
C      RHAT3AC       AREA SPECIFIC MEAN NO. OF AGE 4 FEMALES IN JAN., EST. FROM HAYMAN'S
C                    COHORT ANALYSIS AND ADJUSTED TO OTHER AREAS USING GRD. FSH. SURVEY ESTIMATES.
C      RHAT3BC       DITTO ABOVE
C      RHAT2CC       DITTO ABOVE
C      RHAT2BC       DITTO ABOVE
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C      RHAT3AS       AREA SPECIFIC MEAN NO. OF AGE 4 FEMALES IN JAN., EST. FROM O.D.F.W.
C                    GROUNDFISH SURVEYS 1971-76 ADJUSTED TO A MEAN USING COMPARISONS OF HAYMAN'S
C                    PREDICTED REC WITH OBSERVED ESTIMATES FM GRD FSH SURVEY FOR CORRESPONDING YEARS
C      RHAT3BS       DITTO ABOVE
C      RHAT2CS       DITTO ABOVE
C      RHAT2BS       DITTO ABOVE
C      RLBS(  )(I)   AREA AND AGE SPECIFIC FISH POPULATION IN LBS. AFTER REDISTRIBUTION
C      RPOP(  )     AREA SPECIFIC NUMBERS OF FEMALE ENG. SOLE AFTER REDISTRIBUTION
C      RTONS(  )(I) AREA AND AGES SPECIFIC POPULATION IN METRIC TONNES AFTER REDIST.
C      RYEAR         ANNUAL INDEX FOR BAROMETRIC PRESSURE DATA
C      SBIOM(  )     TOTAL TONS IN SURVIVING POPULATION BY AREA
C      SEALEV        JUNE SEALEVEL AT MEAN DAY IN FEET ABOVE MLLW.
C      SEBIM(  )     TOTAL LBS. IN SURVIVING FISH POPULATION BY AREA
C      SEL(I)        LENGTH SPECIFIC ADJUSTED RATIO OF FISH CAUGHT BY THE FLEET
C      SELB1         PARAMETER FOR THE FLEET SELECTIVITY OGIVE WHICH CONTROLS THE LATERAL PLACEMENT OF THE CURV
C      SELB2         PARAMETER FOR THE FLEET SELECTIVITY OGIVE WHICH CONTROLS THE RATE OF CHANGE OF THE CURVE
C      SFPOP(  )(I) AREA AND AGE SPECIFIC SURVIVING FISH POPULATION IN NOS. OF FEMALE ENG. SOLE
C      SFPOP(I)      AGE SPECIFIC NOS. OF SURVIVING FEMALE ENGLISH SOLE SUMMING AREAS
C      SKNIFE        A SWITCH TO SELECT KNIFE EDGE OR LOGISTIC MESH SELECTIVITY
C      SLBS(  )(I)   AREA AND AGE SPECIFIC SURVIVING FISH POPULATION IN LBS
C      SPOP(  )      AREA SPECIFIC SURVIVING FISH POP IN NOS. OF FEMALE ENGLISH SOLE
C      STONS(  )(I) AREA AND AGES SPECIFIC SURVIVING POPULATION IN METRIC TONNES
C      TBIOM         TOTAL BIOMASS IN METRIC TONNES SUMMING AREAS AND AGES
C      TCATCH        TOTAL AT SEA COMMERCIAL CATCH IN NUMBERS SUMMING AREAS AND AGES
C      TEBIOM        TOTAL BIOMASS IN LBS. SUMMING AREAS AND AGES
C      TEYELD        TOTAL LANDED COMM. CATCH IN LBS. SUMMING AREAS AND AGES
C      TNOT          VON BERTALANFFY  PARAMETER WHICH ADJUSTS TIME AT LENGTH 0
C      TRBIOM        TOTAL TONNES IN REDISTRIBUTED POPULATION
C      TREBIOM       TOTAL LBS. IN REDISTRIBUTED POPULATION
C      TREC          TOTAL RECRUITMENT ALL AREAS COMBINE
C      TRHATC        TOTAL NO. OF AGE 4 FEMALE ENGLSH SOLE ALL AREAS
C                    BASED UPON COHORT ANALYSIS
C      TRHATS        TOTAL NO. OF AGE 4 FEMALE ENGLSH SOLE ALL AREAS
C                    BASED UPON GROUND FISH SURVEY MINI BIOMASS EST. 1971-76
C      TRPOP         TOTAL NUMBER OF REDISTRIBUTED FEMALE ENGLISH SOLE SUMMING AREAS AND AGES
C      TSBIOM        TOTAL METRIC TONNES OF SURVIVING FEMALE ENG. SOLE SUMMED OVER AGE AND AREAS
C      TSEBIOM       TOTAL LBS. OF SURVIVING FEMALE ENG. SOLE OVER AGE AND AREAS
C      TSPOP         TOTAL NUMBER OF SURVIVING FEMALE ENGLSH SOLE SUMMING AREAS AND AGES
C      TYIELD        TOTAL LANDED COMM. CATCH IN M.T. SUMMING AGES AND AREAS
C      UKNIFE        A SWITCH TO SELECT KNIFE EDGE OR LOGISTIC CATCH UTILIZATION
C                    SET UKNIFE=LEN. OF 50% UTILIZATION FOR KNIFE EDGE(DEFAULT UKNIFE=0.0)
C      UTL(  )(I)    AREA AND LENGTH SPECIFIC CATCH UTILIZATION
C      UTLB1         PARAMETER FOR LENGTH SPECIFIC CATCH UTILIZATION  FUNCTION CONTROLING LATERAL PLACEMENT
C      UTLB2         PARAMETER FOR LENGTH SPECIFIC CATCH UTILIZATION FUNCTION CONTROLING SLOPE
C      VARGRO        FLAG TO SELECT MEAN OR VARYING ANNUAL GROWTH
C      VARREC        FLAG TO SELECT MEAN OR VARYING ANNUAL RECRUITMENT
C      VG1        CONSTANT IN THE ANNUALLY VARYING GROWTH FUNCTION, INTERCEPT.
C      VGRCON2       CONSTSNT IN THE ANNUALLY VARYING GROWTH FUNCTION, SLOPE.
C      WT(  )(I)     AREA AND AGE SPECIFIC FISH WEIGHT IN KILOGRAMS
C      WTCONN       EXPONENTIAL LENGTH WEIGHT PARAMETER FOR PMFC 3B-3A
C      WTCONS       EXPONENTIAL LENGTH-WEIGHT PARAMETER FOR PMFC 2B-2C
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C      WTEXPN        LENGTH WEIGHT COEFFICIENT FOR PMFC 3B-3A
C      WTEXPS        LENGTH-WEIGHT COEFFICIENT FOR PMFC 2C-2B
C      YIELD(  )     AREA SPECIFIC TOTAL COMMERCIAL LANDED CATCH IN METRIC TONNES
C      YLBS(  )(I)   AREA AND AGE SPECIFIC YIELD IN LBS.
C      YTONS(  )(I)  AREA AND AGE SPECIFIC YIELD IN METRIC TONNES
C
C---------------FUNCTIONS---------------
C
C-------VON BERTALANFFY GROWTH EQUATION TO ESTIMATE MEAN ANNUAL LENGTH, KREUZ 1979.
C
      VONBERT(LENMAX,K,AGE,TNOT) = LENMAX*(1.-EXP(-(K*(AGE+TNOT))))
C
C------LINEAR RELATIONSHIP BETWEEN SEALEVEL AND BOTTOM TEMPERATURE, KRUSE 80.
C
      BTEMP(B1,B2,SEALEV,B3) = B1+B2*(SEALEV/B3)
C
C-------LINEAR RELATIONSHIP BETWEEN BOTTOM TEMPERATURE AND ANNUAL GROWTH OF AGE 2
C-------FEMALE ENGLISH SOLE, KRUSE ET. AL. 80.
C
      VARYGRO(B1,B2,BTMTEMP)=B1-B2*BTMTEMP
C
C-------EXPONENTIAL LENGTH WEIGHT EQUATION, DEMORY & ROBINSON 72.
C
      WEIGHT(A,FLEN,B)=A*FLEN**B
C
C-------SEASGRO COMPUTES THE PROPORTION OF ACCUMULATED ANNUAL GROWTH
C-------DEPENDENT UPON TIME, MEASURED IN DAYS. KREUZ 1979
C
      SEASGRO(TIME)=1.-1./(1.+EXP(-(4.81-.0294*(TIME))))
C
C-------MATURE COMPUTES LENGTH SPECIFIC PROPORTION MATURE
C
      MATURE(FLEN,B1,B2)=1.-1./(1.+EXP(-(B1-B2*(FLEN))))
C
C-------SELECT COMPUTES LENGTH AND MESH SIZE SPECIFIC
C-------PROPORTION OR RATIO CAUGHT FOR  4.5" MESH, E.A. BEST 1961
C
      SELECT(FLEN,B1,B2)=1.-1./(1.+EXP(-(B1-B2*(FLEN))))
C
C-------RECRUITMENT (AGE FOUR FEMALES) IN AREA 3A IS A FUNCTION OF BAROMETERIC
C-------PRESSURE(UPWELLING), AS OBSERVED BY HAYMAN 1979.
C
      RECRUIT(BAROPRE)=(270.42641*EXP(.00712*BAROPRE))*1000.
C
C-------BARANOV IS THE BARANOV CATCH EQUATION
C
      BARANOV(XN,F,XM,A,FM)=XN*F/(F+XM+A*FM)*(1.-EXP(-F-XM-A*FM))
C
C-------UTILIZE COMPUTES THE LENGTH SPECIFIC UTILIZATION RATE OF CATCH
C-------TENEYCK AND DEMORY (75)
C
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      UTILIZE(FLEN,B1,B2)=1.-1./(1.+EXP(-(B1-B2*(FLEN))))
C
C-------ZMORT COMPUTES SURVIVAL USING NEGATIVE EXPONENTIAL FUNCTION
C
      ZMORT(XN,F,XM,A,FM)=XN*EXP(-(F+XM+A*FM))
C
C-------PORTION OF BARANOV CATCH EQUATION USED TO ITERATIVELY SOLVE FOR THE
C-------MODELED POPULATION'S INSTANTANEOUS FISHING MORTALITY (F)
C
      FUNC(F,XM)=F/(F+XM)*(1.-EXP(-F-XM))
C
C-------------------PROGRAM--------------------
C
C-------ZERO MAJORITY OF ANNUAL TOTALS
C
      EYELD3B=EYELD3A=EYELD2C=EYELD2B=0.0
      TCATCH=TYIELD=TEYELD=0.0
      SBIOM3B=SBIOM3A=SBIOM2C=SBIOM2B=0.0
      SEBIM3B=SEBIM3A=SEBIM2C=SEBIM2B=0.0
      SPOP3B=SPOP3A=SPOP2C=SPOP2B=0.0
      C3B=C3A=C2C=C2B=0.0
      N3B=N3A=N2C=N2B=0.0
      RPOP3B=RPOP3A=RPOP2C=RPOP2B=0.0
      RBIOM3B=RBIOM3A=RBIOM2C=RBIOM2B=0.0
      REBIM3B=REBIM3A=REBIM2C=REBIM2B=0.0
C
C-------AGING OF POPULATIONS
C
      DO 1 I=2,14
         L=16-I
         M=L-1
         SFPOP3B(L)=SFPOP3B(M)
         SFPOP3A(L)=SFPOP3A(M)
         SFPOP2C(L)=SFPOP2C(M)
         SFPOP2B(L)=SFPOP2B(M)
         SFPOP(L)=SFPOP(M)
    1 CONTINUE
C
C-------SELECT ANNUALLY VARYING GROWTH VIA PREDICTIVE MODEL (HAYMAN ET AL)
C-------OR ACTUAL COHORT ESTIMATES OF NOS. AGE 4 FEMALES FROM HAYMAN
C
      IF (COVAREC .EQ. 0.0) GO TO 130
C
C-------INCREMENT VARYING RECRUITMENT YEARS 1959-70 TO READ IN
C-------ACTUAL COHORT ESTIMATES OF NOS. AGE 4 FEMALE FM HAYMAN.
C
      IF (RYEAR .GE. 12) RYEAR=0.0
      RYEAR=RYEAR+1.0
C
C-------READ IN  RECRUITMENT ESTIMATES
C
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      REC3A=RECHAT(RYEAR)
C
C-------COMPUTE VARYING RECRUIMTENT TO EXAMINE SENSITIVITY
C
      REC3A=B*(REC3A-3187083.)+3187083.
      GO TO 131
C
C-------SELECT MEAN ANNUAL OR ANNUALLY VARYING RECRUITMENT (DEFAULT IS MEAN ANNUAL VARREC=0.0)
C
  130 IF (VARREC .EQ. 0.0) GO TO 104
C
C-------INCREMENT VARYING RECRUITMENT DATA YEAR SELECTOR
C-------DATA YEARS ARE 1946-1975 WHILE RECRUITMENT YEARS ARE 1951-1980
C
      IF (RYEAR .EQ. 30.) RYEAR = 0.0
      RYEAR=RYEAR+1.
      BARO=RDATA(RYEAR)
C
C-------SELECT COHORT OR SURVEY ESTIMATES OF NUMBERS RECRUITED.
C-------COHORT=1.0 IS DEFAULT USING HAYMAN'S COHORT ESTIMATES.
C
      IF (COHORT .EQ. 0.0) GO TO 108
C
C-------NO'S OF AGE 4 FEMALES IN AREA 3A IS A FUNCTION OF BAROMETRIC PRESSURE
C
      REC3A=RECRUIT(BARO)
C
C-------COMPUTE INCREASED OR DECREASED RECRUITMENT TO EXAMINE SENSITIVITY
C-------OF RECRUITMENT USING COEFFICIENT OF VARIATION
C
      REC3A=B*(REC3A-RECBARC)+RECBARC
C
C-------NO'S OF AGE 4 FEMALES IN AREAS 3B 2C AND 2B COMPUTED USING RATIOS OF
C-------O.D.F&W. GROUNDFISH SURVEY ESTIMATES AND MEAN COHORT ESTIMATES FROM HAYMAN ET. AL.
C
  131 REC3B=RHAT3BC+((REC3A-RHAT3AC)/RHAT3AC)*RHAT3BC
      REC2C=RHAT2CC+((REC3A-RHAT3AC)/RHAT3AC)*RHAT2CC
      REC2B=RHAT2BC+((REC3A-RHAT3AC)/RHAT3AC)*RHAT2BC
      GO TO 106
C
C-------NO'S OF AGE 4 FEMALES IN AREA 3A AS A FUNCTION OF BAROMETRIC PRESSURE
C-------ADJUSTED TO GRD. FSH. SUR. ESTIMATES.
C
  108 REC3A=(RECRUIT(BARO))*1.4449
C
C-------COMPUTE INCREASED OR DECREASED RECRUITMENT TO EXAMINE SENSITIVITY
C-------OF RECRUITMENT USING COEFFICIENT OF VARIATION
C
      REC3A=B*(REC3A-RECBARS)+RECBARS
C
C-------NO'S OF AGE 4 FEMALES IN AREAS 3B 2C AND 2B COMPUTED USING RATIOS OF
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C-------O.D.F&W. GROUNDFISH SURVEY ESTIMATES AND MEAN COHORT ESTIMATES FROM HAYMAN ET. AL.
C
      REC3B=RHAT3BS+((REC3A-RHAT3AS)/RHAT3AS)*RHAT3BS
      REC2C=RHAT2CS+((REC3A-RHAT3AS)/RHAT3AS)*RHAT2CS
      REC2B=RHAT2BS+((REC3A-RHAT3AS)/RHAT3AS)*RHAT2BS
      GO TO 106
C
C-------SELECT COHORT OR SURVEY ESTIMATES OF CONSTANT MEAN RECRUITMENT
C
  104 IF (COHORT .EQ. 0.0) GO TO 105
C
C-------MEAN RECRUITMENT VIA COHORT ESTIMATES HAYMAN ET.AL. 80
C
      REC3B=RHAT3BC*B
      REC3A=RHAT3AC*B
      REC2C=RHAT2CC*B
      REC2B=RHAT2BC*B
      GO TO 106
C
C-------MEAN RECRUITMENT VIA GROUND FSH SURVEY EST. ODF&W (DEMORY)
C
  105 REC3B=RHAT3BS*B
      REC3A=RHAT3AS*B
      REC2C=RHAT2CS*B
      REC2B=RHAT2BS*B
C
C-------COMPUTE TOTAL RECRUITMENT ALL PMFC AREAS COMBINE
C
  106 TREC=REC3B+REC3A+REC2C+REC2B
C
C-------SFPOP(5) IS ACTUALLY THE RECRUITED POP NOT THE SURVIVING POP
C-------FOR COMPUTATIONAL PURPOSES AND SFPOP(5) IS LAST YEARS RECRUITS
C
      SFPOP(5)=TREC
C
C-------RECRUITMENT---AGE AT ENTRY INTO MODEL
C-------AGE OF RECRUITMENT IS AGE 4 HOWEVER,
C-------THESE FISH ARE IN THEIR 5TH YEAR OF LIFE AND
C-------ARE INDEXED AS FIVES IN THE SIMULATION MODEL.
C
      SFPOP3B(5)=REC3B
      SFPOP3A(5)=REC3A
      SFPOP2C(5)=REC2C
      SFPOP2B(5)=REC2B
C
C-------SELECT AVERAGE LENGTH AT AGE USING VON BERTALANFFY
C-------AND AVERAGE TIME OR VON BERT. AND SEASONAL GROWTH
C
      IF (VONB .EQ. 0.0) GO TO 101
C
C-------COMPUTE AVERAGE ANNUAL LENGTH AT AGE USING VON BERTALANFFY
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C-------EQUATION WITH TIME (T) = TO THAT FRACTION OF YEAR WHEN HALF
C-------THE COMMERCIAL CATCH IS LANDED.
C
      DO 501 I=2,14
             J=I-1
             AVLEN3B(I)=VONBERT(LENMAX,K,FLOAT(J)+DAYS3B/365.,TNOT)
             AVLEN3A(I)=VONBERT(LENMAX,K,FLOAT(J)+DAYS3A/365.,TNOT)
             AVLEN2C(I)=VONBERT(LENMAX,K,FLOAT(J)+DAYS2C/365.,TNOT)
             AVLEN2B(I)=VONBERT(LENMAX,K,FLOAT(J)+DAYS2B/365.,TNOT)
  501 CONTINUE
             AVLEN3B(1)=VONBERT(LENMAX,K,DAYS3B/365.,TNOT)
             AVLEN3A(1)=VONBERT(LENMAX,K,DAYS3A/365.,TNOT)
             AVLEN2C(1)=VONBERT(LENMAX,K,DAYS2C/365.,TNOT)
             AVLEN2B(1)=VONBERT(LENMAX,K,DAYS2B/365.,TNOT)
             GO TO 700
C
C-------SELECT MEAN ANNUAL GROWTH OR ANNUALLY VARYING GROWTH
C-------DEFAULT MEAN ANNUAL GROWTH (VARGRO=0.0)
C
  101 IF (VARGRO .LT. 1.0) GO TO 102
C
C-------CHECK LENGTH COMPUTE SWITHC TO SKIP VONBERT AFTER 1ST ITERATION
C
      IF (LENFLAG .EQ. 1.0) GO TO 103
C
C-------CALCULATE AREAS INITIAL MEAN ANNUAL LENGTHS
C
      DO 3 I=1,14
         ANLEN3B(I)=VONBERT(LENMAX,K,FLOAT(I),TNOT)
         ANLEN3A(I)=VONBERT(LENMAX,K,FLOAT(I),TNOT)
         ANLEN2C(I)=VONBERT(LENMAX,K,FLOAT(I),TNOT)
         ANLEN2B(I)=VONBERT(LENMAX,K,FLOAT(I),TNOT)
    3 CONTINUE
      LENFLAG=1.0
C
C-------ANNUALLY VARYING GROWTH
C-------DRIVEN BY SEALEVEL FOR AGE 2, USING DATA FROM 1951-1980.
C
  103 IF (GYEAR .EQ. 30.) GYEAR = 0.0
      GYEAR=GYEAR+1.
      SEALEV=GDATA(GYEAR)
      BTMTEMP=BTEMP(BTCON1,BTCON2,SEALEV,BTCON3)
         ANVGR3B(1)=ANLEN3B(1)
         ANVGR3A(1)=ANLEN3A(1)
         ANVGR2C(1)=ANLEN2C(1)
         ANVGR2B(1)=ANLEN2B(1)
            ANVGR3A(2)=VARYGRO(VGRCON1,VGRCON2,BTMTEMP)
C
C-------COMPUTE INCREASED OR DECREASED ANNUAL VARYING GROWTH FOR SENSITIVITY
C-------ANALYSIS, USING COEFFICIENT OF VARIATION
C
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          ANVGR3A(2)=D*(ANVGR3A(2)-GROBAR)+GROBAR
C
C-------SET GROWTH AMOUNG AREAS EQUAL FOR AGE 2 FISH
C
          ANVGR3B(2)=ANVGR2C(2)=ANVGR2B(2)=ANVGR3A(2)
C
C-------ADJUST GROWTH AT SUCESSIVE AGES (3-13) BY PROPORTION OF AGE 2
C
             DO 2 I=3,14
             ANVGR3A(I)=PCT(I)*ANVGR3A(2)
C
C-------SET GROWTH AT AGES (3-13) EQUAL OVER AREAS
C
             ANVGR3B(I)=ANVGR2C(I)=ANVGR2B(I)=ANVGR3A(I)
    2        CONTINUE
C
C-------UPDATE ANNUAL LENGTH (CM. TOTAL LENGTH) AT AGE
C-------TO ALLOW ACCUMMULATIVE EFFECTS OF VARYING GROWTH
C
      DO 6 I=2,14
       L=16-I
       M=L-1
          ANLEN3B(L)=ANLEN3B(M)+ANVGR3B(L)
          ANLEN3A(L)=ANLEN3A(M)+ANVGR3A(L)
          ANLEN2C(L)=ANLEN2C(M)+ANVGR2C(L)
          ANLEN2B(L)=ANLEN2B(M)+ANVGR2B(L)
    6 CONTINUE
      GO TO 140
C
C-------CHECK ANNUAL LENGTH COMPUTAION SWITCH
C
  102 IF (GRSWTCH .EQ. 1.0) GO TO 150
C
C-------CALCULATE AREAS INITIAL MEAN ANNUAL LENGTHS
C
      DO 30 I=1,14
         ANLEN3B(I)=VONBERT(LENMAX,K,FLOAT(I),TNOT)
         ANLEN3A(I)=VONBERT(LENMAX,K,FLOAT(I),TNOT)
         ANLEN2C(I)=VONBERT(LENMAX,K,FLOAT(I),TNOT)
         ANLEN2B(I)=VONBERT(LENMAX,K,FLOAT(I),TNOT)
   30 CONTINUE
      GRSWTCH = 1.0
C
C-------CALCULATE AREA SPECIFIC MEAN ANNUAL GROWTH INCREMENTS
C
  150 IF (GROFLAG .EQ. 1.0) GO TO 140
      ANVGR3B(1)=ANGRO3B(1)=ANLEN3B(1)
      ANVGR3A(1)=ANGRO3A(1)=ANLEN3A(1)
      ANVGR2C(1)=ANGRO2C(1)=ANLEN2C(1)
      ANVGR2B(1)=ANGRO2B(1)=ANLEN2B(1)
      DO 4 I=2,14
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          ANVGR3B(I)=ANGRO3B(I)=(ANLEN3B(I)-ANLEN3B(I-1))
          ANVGR3A(I)=ANGRO3A(I)=(ANLEN3A(I)-ANLEN3A(I-1))
          ANVGR2C(I)=ANGRO2C(I)=(ANLEN2C(I)-ANLEN2C(I-1))
          ANVGR2B(I)=ANGRO2B(I)=(ANLEN2B(I)-ANLEN2B(I-1))
    4 CONTINUE
      GROFLAG=1.0
C
C-------COMPUTE AVERAGE ANNUAL GROWTH ADJUSTED TO
C-------COINCIDE WITH SEASONAL GROWTH (KREUZ 79).
C
  140 DO 5 I=1,14
          AVGRO3B(I)=ANVGR3B(I)*SEASGRO(DAYS3B)
          AVGRO3A(I)=ANVGR3A(I)*SEASGRO(DAYS3A)
          AVGRO2C(I)=ANVGR2C(I)*SEASGRO(DAYS2C)
          AVGRO2B(I)=ANVGR2B(I)*SEASGRO(DAYS2B)
    5 CONTINUE
C
C-------COMPUTE AVERAGE ANNUAL LENGTH AT AGE
C-------TO ALLOW ACCUMULATIVE EFFECTS OF VARYING GROWTH
C
      DO 7 I=2,14
         L=16-I
         M=L-1
            AVLEN3B(L)=ANLEN3B(M)+AVGRO3B(L)
            AVLEN3A(L)=ANLEN3A(M)+AVGRO3A(L)
            AVLEN2C(L)=ANLEN2C(M)+AVGRO2C(L)
            AVLEN2B(L)=ANLEN2B(M)+AVGRO2B(L)
    7 CONTINUE
            AVLEN3B(1)=AVGRO3B(1)
            AVLEN3A(1)=AVGRO3A(1)
            AVLEN2C(1)=AVGRO2C(1)
            AVLEN2B(1)=AVGRO2B(1)
C
C-------UPDATE MEAN ANNUAL WEIGHT (GRAMS) AT LENGTH (BARSS ET. AL. 1977)
C
  700 DO 8 I=1,14
          WT3B(I)=WEIGHT(WTCONN,AVLEN3B(I),WTEXPN)
          WT3A(I)=WEIGHT(WTCONN,AVLEN3A(I),WTEXPN)
C
C-------UPDATE MEAN ANNUAL WEIGHT (GRAMS) AT LENGTH (DEMORY ET. AL. 1975)
C
          WT2C(I)=WEIGHT(WTCONS,AVLEN2C(I),WTEXPS)
          WT2B(I)=WEIGHT(WTCONS,AVLEN2B(I),WTEXPS)
C
C-------CHECK IF REDISTRIBUTION IS ON
C
      IF (REDIST .EQ. 0.) GO TO 21
C
C-------COMPUTE LENGTH SPECIFIC PERCENT MATURE
C
          MATUR3B(I)=MATURE(AVLEN3B(I),MTRB1,MTRB2)
```

```
      MATUR3A(I)=MATURE(AVLEN3A(I),MTRB1,MTRB2)
      MATUR2C(I)=MATURE(AVLEN2C(I),MTRB1,MTRB2)
      MATUR2B(I)=MATURE(AVLEN2B(I),MTRB1,MTRB2)
C
C-------COMPUTE LENGTH SPECIFIC PERCENT IMMATURE
C
         IMATR3B(I)=1.0-MATUR3B(I)
         IMATR3A(I)=1.0-MATUR3A(I)
         IMATR2C(I)=1.0-MATUR2C(I)
         IMATR2B(I)=1.0-MATUR2B(I)
C
C-------SELECT COHORT OR SURVEY BASED DISTRIBUTION ESTIMATES
C
      IF (COHORT .EQ. 0.0) GO TO 100
C
C-------REDISTRIBUTE MATURE SURVIVING POPULATION TO PMFC AREAS USING
C-------PROPORTIONS THAT SATISFY AVERAGE CATCHS OBSERVED IN THESE AREAS
C-------AND COHORT BASED RECRUITMENT ESTIMATES
C
      RFPOP3B(I)=SFPOP(I)*MATUR3B(I)*DIST3BC
      RFPOP3A(I)=SFPOP(I)*MATUR3A(I)*DIST3AC
      RFPOP2C(I)=SFPOP(I)*MATUR2C(I)*DIST2CC
      RFPOP2B(I)=SFPOP(I)*MATUR2B(I)*DIST2BC
      GO TO 99
C
C-------REDISTRIBUTE MATURE SURVIVING POPULATION TO PMFC AREAS USING
C-------PROPORTIONS THAT SATISFY AVERAGE CATCHS OBSERVED IN THESE AREAS
C-------AND SURVEY BASED RECRUITMENT ESTIMATES.
C
  100 RFPOP3B(I)=SFPOP(I)*MATUR3B(I)*DIST3BS
      RFPOP3A(I)=SFPOP(I)*MATUR3A(I)*DIST3AS
      RFPOP2C(I)=SFPOP(I)*MATUR2C(I)*DIST2CS
      RFPOP2B(I)=SFPOP(I)*MATUR2B(I)*DIST2BS
C
C-------REDISTRIBUTE IMMATURE SURVIVING POPULATION TO PMFC AREAS USING
C-------PROPORTION OF AGE FOUR GROUND FISH SURVEY ABUNDANCES ESTIMATES
C
   99    RFPOP3B(I)=RFPOP3B(I)+SFPOP(I)*IMATR3B(I)*(RHAT3BS/TRHATS)
         RFPOP3A(I)=RFPOP3A(I)+SFPOP(I)*IMATR3A(I)*(RHAT3AS/TRHATS)
         RFPOP2C(I)=RFPOP2C(I)+SFPOP(I)*IMATR2C(I)*(RHAT2CS/TRHATS)
         RFPOP2B(I)=RFPOP2B(I)+SFPOP(I)*IMATR2B(I)*(RHAT2BS/TRHATS)
         GO TO 22
C
C-------NONREDISTRIBUTED POPULATION
C
   21 RFPOP3B(I)=SFPOP3B(I)
      RFPOP3A(I)=SFPOP3A(I)
      RFPOP2C(I)=SFPOP2C(I)
      RFPOP2B(I)=SFPOP2B(I)
C
C-------SUM REDISTRIBUTED POP BY AGE OVER AREAS
```

```
C
   22 RFPOP(I)=RFPOP3B(I)+RFPOP3A(I)+RFPOP2C(I)+RFPOP2B(I)
    9 CONTINUE
C
C-------CHECK IF QUOTA ON
C
      IF (QUOTA .EQ. 0.0) GO TO 107
C
C-------INITIALIZE QUOTA PARAMETERS
C
      F3B=F3A=F2C=F2B=2.56
      IQ=0
C
C-------ZERO REMAINDER OF ANNUAL TOTALS
C
  107 TOTCC3B=TOTCC3A=TOTCC2C=TOTCC2B=0.0
      YIELD3B=YIELD3A=YIELD2C=YIELD2B=0.0
      DO 9 I=1,14
      SEL3B(I)=SEL3A(I)=SEL2C(I)=SEL2B(I)=0.0
      UTL3B(I)=UTL3A(I)=UTL2C(I)=UTL2B(I)=0.0
      CATCH3B(I)=CATCH3A(I)=CATCH2C(I)=CATCH2B(I)=0.0
C
C-------SELECT KNIFE EDGE OR LOGISTIC TRAWL SELECTIVITY
C
      IF (SKNIFE .NE. 0.0) GO TO 120
C
C--------COMPUTE LENGTH SPECIFIC TRAWL SELECTIVITY
C
         SEL3B(I)=SELECT(AVLEN3B(I),SELB1,SELB2)
         SEL3A(I)=SELECT(AVLEN3A(I),SELB1,SELB2)
         SEL2C(I)=SELECT(AVLEN2C(I),SELB1,SELB2)
         SEL2B(I)=SELECT(AVLEN2B(I),SELB1,SELB2)
         GO TO 121
C
C-------KNIFE EDGE MESH SELECTION AT 29.1566 C.M. TOTAL LENGTH
C-------50 PERCENT SELECTION FOR 4.5 INCH MESH TRAWL, E. A. BEST 1961.
C
  120 IF (AVLEN3B(I) .GE. SKNIFE) SEL3B(I)=1.0
      IF (AVLEN3A(I) .GE. SKNIFE) SEL3A(I)=1.0
      IF (AVLEN2C(I) .GE. SKNIFE) SEL2C(I)=1.0
      IF (AVLEN2B(I) .GE. SKNIFE) SEL2B(I)=1.0
C
C-------SELECT KNIFE EDGE OR LOGISTIC CATCH UTILIZATION
C
  121 IF (UKNIFE .NE. 0.0) GO TO 122
C
C-------COMPUTE LENGTH SPECIFIC CATCH UTILIZATION
C
      UTL3B(I)=UTILIZE(AVLEN3B(I),UTLB1,UTLB2)
      UTL3A(I)=UTILIZE(AVLEN3A(I),UTLB1,UTLB2)
      UTL2C(I)=UTILIZE(AVLEN2C(I),UTLB1,UTLB2)
```

```
      UTL2B(I)=UTILIZE(AVLEN2B(I),UTLB1,UTLB2)
      GO TO 123
C
C-------KNIFE EDGE CATCH UTILIZATION AT 25.9368 C.M. TOTAL LENGTH = 50
C-------PERCENT SELECTION FROM CATCH UTILIZATION STUDY TENEYCK AND DEMORY 75.
C
  122 IF (AVLEN3B(I) .GE. UKNIFE) UTL3B(I)=1.0
      IF (AVLEN3A(I) .GE. UKNIFE) UTL3A(I)=1.0
      IF (AVLEN2C(I) .GE. UKNIFE) UTL2C(I)=1.0
      IF (AVLEN2B(I) .GE. UKNIFE) UTL2B(I)=1.0
C
C-------COMPUTE LENGTH SPECIFIC FRACTION OF CATCH DISCARDED
C
  123 DSCRD3B(I)=1.0-UTL3B(I)
      DSCRD3A(I)=1.0-UTL3A(I)
      DSCRD2C(I)=1.0-UTL2C(I)
      DSCRD2B(I)=1.0-UTL2B(I)
C
C-------COMPUTE LENGTH SPECIFIC INSTANTANEOUS FISHING MORTALITY
C-------ADJUSTED FOR MESH SELECTION AND AT SEA DISCARDING
C
      FMORT3B(I)=SEL3B(I)*UTL3B(I)*F3B
      FMORT3A(I)=SEL3A(I)*UTL3A(I)*F3A
      FMORT2C(I)=SEL2C(I)*UTL2C(I)*F2C
      FMORT2B(I)=SEL2B(I)*UTL2B(I)*F2B
C
C-------COMPUTE LENGTH SPECIFIC INSTANTANEOUS MORTALITY DUE TO FISHING
C
      DMORT3B(I)=DSCRD3B(I)*SEL3B(I)*F3B
      DMORT3A(I)=DSCRD3A(I)*SEL3A(I)*F3A
      DMORT2C(I)=DSCRD2C(I)*SEL2C(I)*F2C
      DMORT2B(I)=DSCRD2B(I)*SEL2B(I)*F2B
C
C-------COMPUTE VESSEL CATCH AT AGE BY AREA
C
         CATCH3B(I)=BARANOV(RFPOP3B(I),FMORT3B(I),NMORT,A,DMORT3B(I))
         CATCH3A(I)=BARANOV(RFPOP3A(I),FMORT3A(I),NMORT,A,DMORT3A(I))
         CATCH2C(I)=BARANOV(RFPOP2C(I),FMORT2C(I),NMORT,A,DMORT2C(I))
         CATCH2B(I)=BARANOV(RFPOP2B(I),FMORT2B(I),NMORT,A,DMORT2B(I))
C
C-------COMPUTE LANDED CATCH TOTALS BY AREA
C
         TOTCC3B=TOTCC3B+CATCH3B(I)
         TOTCC3A=TOTCC3A+CATCH3A(I)
         TOTCC2C=TOTCC2C+CATCH2C(I)
         TOTCC2B=TOTCC2B+CATCH2B(I)
C
C-------WT. OF LANDINGS BY AGE IN M.T.
C
         YTONS3B(I)=CATCH3B(I)*WT3B(I)/1000000
         YTONS3A(I)=CATCH3A(I)*WT3A(I)/1000000
```

```
      YTONS2C(I)=CATCH2C(I)*WT2C(I)/1000000
      YTONS2B(I)=CATCH2B(I)*WT2B(I)/1000000
C
C-------SUM OF LANDINGS BY AGES IN M.T.
C
      YIELD3B=YIELD3B+YTONS3B(I)
      YIELD3A=YIELD3A+YTONS3A(I)
      YIELD2C=YIELD2C+YTONS2C(I)
      YIELD2B=YIELD2B+YTONS2B(I)
    9 CONTINUE
      XYTONS=YTONS3A(5)+YTONS3A(6)+YTONS3A(7)+YTONS3A(8)
C
C-------SUM TOTAL CATCHES IN METRIC TONNES
C
      TYIELD = YIELD3B+YIELD3A+YIELD2C+YIELD2B
C
C-------CHECK IF QUOTA ON
C
      IF(QUOTA .EQ. 0.) GO TO 110
C
C-------WHEN QUOTA IS ON, FIND THE F WHOSE YIELD JUST MEETS OR EXCEEDS
C-------THE QUOTA. THIS ALGORITHM USES INTERVAL HALVING TO SEARCH FOR F
C-------BETWEEN 0.0 AND 5.12 WHERE F=5.12 IS MORE THAN 99% MORTALITY
C
      IQ = IQ + 1
      IF (IQ .GT. 9) GO TO 110
      IF (TYIELD .GT. QUOTA) GO TO 210
C
C-------IF TOTAL YIELD IS LESS THAN QUOTA INCREMENT F AND GO AROUND AGAIN
C
      F3B = F3B + FINC(IQ)
      F3A = F3A + FINC(IQ)
      F2C = F2C + FINC(IQ)
      F2B = F2B + FINC(IQ)
      GO TO 107
C
C-------OTHERWISE, DECREMENT F UNLESS THE LAST CHANGE IN F WAS ONLY .01 UNIT
C-------IN WHICH CASE WE ARE THROUGH.
C
  210 IF (IQ .EQ. 9) GO TO 110
      F3B = F3B - FINC(IQ)
      F3A = F3A - FINC(IQ)
      F2C = F2C - FINC(IQ)
      F2B = F2B - FINC(IQ)
      GO TO 107
C
C-------SUM VARIOUS CATCH STATS OVER AGES WITHIN AREAS
C
  110 DO 10 I=1,14
C
C-------COMPUTE WEIGHT OF LANDINGS IN LBS. BY AGE AND AREA
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```
C
      YLBS3B(I)=YTONS3B(I)*2204.6
      YLBS3A(I)=YTONS3A(I)*2204.6
      YLBS2C(I)=YTONS2C(I)*2204.6
      YLBS2B(I)=YTONS2B(I)*2204.6
C
C-------SUM OF LANDINGS IN LBS. BY AGE AND AREA.
C
      EYELD3B=EYELD3B+YLBS3B(I)
      EYELD3A=EYELD3A+YLBS3A(I)
      EYELD2C=EYELD2C+YLBS2C(I)
      EYELD2B=EYELD2B+YLBS2B(I)
C
C-------COMPUTE PERCENT AGE COMPOSITION OF LANDED COMM. CATCH
C
      IF (F3B .NE. 0.) PCTCP3B(I)=CATCH3B(I)/TOTCC3B
      IF (F3A .NE. 0.) PCTCP3A(I)=CATCH3A(I)/TOTCC3A
      IF (F2C .NE. 0.) PCTCP2C(I)=CATCH2C(I)/TOTCC2C
      IF (F2B .NE. 0.) PCTCP2B(I)=CATCH2B(I)/TOTCC2B
   10 CONTINUE
C
C-------SUM TOTAL CATCHES IN NUMBERS AND POUNDS
C
      TCATCH = TOTCC3B+TOTCC3A+TOTCC2C+TOTCC2B
      TEYELD = EYELD3B+EYELD3A+EYELD2C+EYELD2B
C
C-------COMPUTE AREA SPECIFIC NEGATIVE EXPONENTIAL SURVIVAL USING CONSTANT
C-------INSTANTANEOUS NATURAL MORTALITY (NMORT) AND AGE SPECIFIC INSTANTAEOUS
C-------FISHING MORTALITY (FMORT) WHICH INCLUDES AT SEA DISCARDING AND
C-------(A) THE FRACTION OF DISCARDS THAT DIE, AND MORTALITY DUE TO FISHING (DMORT).
C
      DO 11 I=1,14
         SFPOP3B(I)=ZMORT(RFPOP3B(I),FMORT3B(I),NMORT,A,DMORT3B(I))
         SFPOP3A(I)=ZMORT(RFPOP3A(I),FMORT3A(I),NMORT,A,DMORT3A(I))
         SFPOP2C(I)=ZMORT(RFPOP2C(I),FMORT2C(I),NMORT,A,DMORT2C(I))
         SFPOP2B(I)=ZMORT(RFPOP2B(I),FMORT2B(I),NMORT,A,DMORT2B(I))
C
C-------SUM SURVIVING AGES OVER AREAS
C
         SFPOP(I)=SFPOP3B(I)+SFPOP3A(I)+SFPOP2C(I)+SFPOP2B(I)
C
C-------COMPUTE SURVIVING POPULATION TONS AND POUNDS AT AGE WITHIN AREA
C
         STONS3B(I)=SFPOP3B(I)*WT3B(I)/1000000
         STONS3A(I)=SFPOP3A(I)*WT3A(I)/1000000
         STONS2C(I)=SFPOP2C(I)*WT2C(I)/1000000
         STONS2B(I)=SFPOP2B(I)*WT2B(I)/1000000
         SLBS3B(I)=STONS3B(I)*2204.6
         SLBS3A(I)=STONS3A(I)*2204.6
         SLBS2C(I)=STONS2C(I)*2204.6
         SLBS2B(I)=STONS2B(I)*2204.6
```

```
C
C-------SUM SURVIVING POPULATION NOS. IN M.T. & LBS. OVER AGES BY AREAS
C
          SPOP3B = SPOP3B + SFPOP3B(I)
          SPOP3A = SPOP3A + SFPOP3A(I)
          SPOP2C = SPOP2C + SFPOP2C(I)
          SPOP2B = SPOP2B + SFPOP2B(I)
          SBIOM3B = SBIOM3B + STONS3B(I)
          SBIOM3A = SBIOM3A + STONS3A(I)
          SBIOM2C = SBIOM2C + STONS2C(I)
          SBIOM2B = SBIOM2B + STONS2B(I)
          SEBIM3B = SEBIM3B + SLBS3B(I)
          SEBIM3A = SEBIM3A + SLBS3A(I)
          SEBIM2C = SEBIM2C + SLBS2C(I)
          SEBIM2B = SEBIM2B + SLBS2B(I)
   11 CONTINUE
C
C------SUM SURVIVING FISH NOS., M.T., & LBS. OVER  AREAS
C
      TSPOP = SPOP3B + SPOP3A + SPOP2C + SPOP2B
      TSBIOM = SBIOM3B + SBIOM3A + SBIOM2C + SBIOM2B
      TSEBIOM = SEBIM3B + SEBIM3A + SEBIM2C + SEBIM2B
C
C-------COMPUTE AREA SPECIFIC CATCH AND POP FOR AGES 6 AND GREATER
C-------FOR COMPUTING F OVER MODELED AREA
C
      DO 12 I=6,14
             C3B=C3B+CATCH3B(I)
             C3A=C3A+CATCH3A(I)
             C2C=C2C+CATCH2C(I)
             C2B=C2B+CATCH2B(I)
             N3B=N3B+SFPOP3B(I)
             N3A=N3A+SFPOP3A(I)
             N2C=N2C+SFPOP2C(I)
             N2B=N2B+SFPOP2B(I)
   12 CONTINUE
C
C-------SUM AREA SPECIFIC CATCH AND POP, AGES 6 AND GREATER
C
      C=C3B+C3A+C2C+C2B
      N=N3B+N3A+N2C+N2B
      IF (N .EQ. 0.) N = 1.0
C
C-------ALGORITHM FOR COMPUTING TOTAL POPULATION INSTANTANEOUS FISHING MORTALITY
C-------USING BARANOV CATCH EQUATION CATCH AND POP FOR AGE 6 AND GREATERAND NATURAL MORTALITY
C
      F = 2.56
      IQ = 0.
  300 IQ = IQ + 1
      IF (IQ .GT. 9) GO TO 400
      IF (FUNC(F.NMORT) .GT. C/N) GO TO 310
```

```
      F = F + FINC(IQ)
      GO TO 300
  310 IF (IQ .EQ. 9) GO TO 400
      F = F - FINC(IQ)
      GO TO 300
  400 DO 20 I=1,14
C
C-------COMPUTE REDISTRIBUTED POPULATION TONS AND POUNDS AT AGE WITHIN AREA
C
        RTONS3B(I)=RFPOP3B(I)*WT3B(I)/1000000
        RTONS3A(I)=RFPOP3A(I)*WT3A(I)/1000000
        RTONS2C(I)=RFPOP2C(I)*WT2C(I)/1000000
        RTONS2B(I)=RFPOP2B(I)*WT2B(I)/1000000
        RLBS3B(I)=RTONS3B(I)*2204.6
        RLBS3A(I)=RTONS3A(I)*2204.6
        RLBS2C(I)=RTONS2C(I)*2204.6
        RLBS2B(I)=RTONS2B(I)*2204.6
C
C-------SUM REDISTRIBUTED POPULATION NOS. IN M.T. & LBS. OVER AGES BY AREAS
C
        RPOP3B = RPOP3B + RFPOP3B(I)
        RPOP3A = RPOP3A + RFPOP3A(I)
        RPOP2C = RPOP2C + RFPOP2C(I)
        RPOP2B = RPOP2B + RFPOP2B(I)
        RBIOM3B = RBIOM3B + RTONS3B(I)
        RBIOM3A = RBIOM3A + RTONS3A(I)
        RBIOM2C = RBIOM2C + RTONS2C(I)
        RBIOM2B = RBIOM2B + RTONS2B(I)
        REBIM3B = REBIM3B + RLBS3B(I)
        REBIM3A = REBIM3A + RLBS3A(I)
        REBIM2C = REBIM2C + RLBS2C(I)
        REBIM2B = REBIM2B + RLBS2B(I)
   20 CONTINUE
C
C------SUM REDISTRIBUTED POP NOS., M.T., & LBS. OVER  AREAS
C
      TRPOP = RPOP3B + RPOP3A + RPOP2C + RPOP2B
      TRBIOM = RBIOM3B + RBIOM3A + RBIOM2C + RBIOM2B
      TREBIOM = REBIM3B + REBIM3A + REBIM2C + REBIM2B
      RETURN
      END
C
C-------SUBROUTINE EXTENDS SIMCON COMMON BLOCK LIMITS
C
      SUBROUTINE CCOM
      COMMON DUMMY(1700)
      RETURN
      END
C
C-------SUBROUTINE TO EXTEND  SYMBOL TABLE LENGTH
C
```