Yield Loss of Western Alaska Chinook Salmon Resulting from the Foreign Groundfish Fishery in the Bering Sea in 1979

by

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YIELD LOSS OF WESTERN ALASKA CHINOOK SALMON
RESULTING FROM THE FOREIGN GROUNDFISH FISHERY IN THE BERING SEA IN 1979[1/]

Large catches of chinook salmon by foreign fleets fishing in the Bering Sea in 1979 and 1980 generated considerable interest in the possible effects of the oceanic fisheries on the chinook salmon resource of western Alaska. Two fisheries are involved. The foreign groundfish fishery took 100,167 chinook salmon in the Bering Sea in 1979, and 114,925 in 1980; and the Japanese salmon mothership fishery took a record-high 703,798 chinook salmon in 1980. Roughly 60% of the 1980 mothership catch was in the Bering Sea and 40% in the North Pacific Ocean -- but in either case all were taken in areas where western Alaska chinook salmon are known to occur.

Because most chinook salmon taken at sea are immature and not due to return inshore until 1-4 years later, one potential effect of offshore fishing is differential yield -- the change in mass between fish caught at sea, and (assuming that there had been no high-seas fishery), the survivors of the same fish inshore. Because the weight of the survivors reaching the coast always exceeds the weight of the catch at sea, studies of differential yield are, in fact, studies of yield loss (Ricker 1976).

In an earlier paper (Major 1982), I reported that the yield-loss ratio associated with one of the fisheries mentioned above, the Japanese salmon mothership operation of 1980, was 6.52. That is to say that for every kilogram of fish landed at sea in 1980, 6.52 kilograms would have eventually made it to the coast had the 1980 high-seas fishery not taken place. This was the

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[1/]Use of the term "western Alaska" does not ignore an unmeasured proportion of Yukon River chinook salmon originating in Canada.

highest yield-loss ratio yet reported for Pacific salmon -- greatly exceeding the highest values similarly computed earlier (3.78 for chum salmon [Ricker 1964] and 3.96 for sockeye salmon [Fredin 1964]). Because each of the 3 situations compared above (Major 1982; Ricker 1964; and Fredin 1964) involved a gillnet fishery, noncatch mortalities associated with high-seas gillnetting were included in the computations. The inclusion of noncatch losses tends to inflate the ratios, but not without basis. Ricker (1976) reported that for every immature salmon landed by gillnets at sea, another is killed but not landed, and that for every 3 mature salmon landed, one is killed but not landed. No one has yet suggested that there are noncatch mortalities associated with trawling -- the method by which virtually all salmon are taken in the groundfish fishery. It follows, therefore, that yield-loss ratios computed for trawl-caught salmon will be less than those reported above for those caught in gillnets.

In this paper, I estimate the potential yield loss of western Alaska chinook salmon resulting from the foreign groundfish fishery in the Bering Sea in 1979 and compare the results to estimates of yield loss reported earlier in studies of salmon taken on the high seas by gillnets. Similar estimates have not been developed for the 1980 foreign groundfish catch because information about the ocean-age composition of the 1980 catch is lacking.

CALCULATION OF YIELD LOSS

Yield loss, as it was computed in the studies referenced above and as it will be computed here, indicates the foreclosed gain that could have been realized by the discontinuation of ocean fishing in terms of the weight of the catch taken on the high seas. Let (m) be the change in mass from the time of ocean fishery to the time the fish reach the coast and the ratio of catches without and with ocean fishing becomes

$$\frac{Hm}{H} = \frac{He^{(g-q)t}}{H}$$

where H is the weight of the high-seas catch, (g) is the monthly instantaneous growth rate, (q) is the monthly instantaneous mortality rate, and (t) is the time in months between the high-seas fishery and the time the fish reach the coast.

In this paper, change in mass is calculated separately for 99 cells -- each consisting of a unique combination of the following categories:

sex, ocean age, and 3-month period -- at time of capture in the high-seas fishery

ocean age -- at time of maturity

Each cell is weighted according to its representation in the total catch of western Alaska fish in the 1979 foreign groundfish fishery. Hence the potential change in mass becomes

$$m = \sum_{c=1}^{99} w_c e^{(g_c - q_c)t_c}$$

where the added considerations are cell (c) and weighting factor (w).

The foregoing procedure requires the following information:

(1) sex and ocean-age composition of western Alaska chinook salmon in the foreign groundfish fishery in the Bering Sea by 3-month period;

(2) growth;

(3) natural mortality;

(4) maturity schedule.

The derivation of this information is presented in the subsections that follow. For each of the key variables involved (proportion of western Alaska fish in the high-seas catch, growth, natural mortality, and maturity schedule), the text discussion is developed in terms of average values or best estimates. The sensitivity analysis of the yield-loss estimate to changes in the four variables is discussed separately in the final section of the paper.

Sex and ocean-age composition

The sex and ocean-age composition of western Alaska chinook salmon taken in the foreign groundfish fishery in the Bering Sea in 1979 is presented in Table 1. Total catch of chinook salmon, without regard to continent of origin, was estimated from Nelson et al. (1980) who reported that 107,706 salmon were taken (all species combined) of which 93% (100,167) were chinook salmon. This number, treated by 3-month quarterly periods, was partitioned by sex and ocean-age on the basis of samples analyzed by Rogers et al. (1982). Finally, for purposes of the text run of the model, it was assumed that 90% of the chinook salmon in each category were of western Alaska origin. This assumption seems reasonable in that nearly all catches were in or toward western Alaska from the north-south corridor bracketed by 180° and 175°W -- an area where earlier studies (Major et al. 1977) showed 93% of the chinook salmon sampled in the summer to be of western Alaska origin (Figure 1).2/

Growth and natural mortality

As reported in the earlier study to measure yield-loss associated with the Japanese high-seas mothership fishery (Major 1982), there have been no definitive studies of the growth of chinook salmon in the ocean, particularly in terms of weight. Consequently, growth, as it is estimated here, is the

2/ More specifically, Major et al. (1977) showed that where only two possibilities existed (Asian or western Alaskan), 93% were western Alaskan. The recovery (barely north of the Aleutian Islands in 1982) of two tagged chinook salmon--one from central Alaska and another from Oregon--gives faint suggestion that all North American stocks should be included in any scheme to partition Bering Sea chinook salmon into their component parts. However, being that the vast majority of the 1979 catch was taken far to the the northwest of the area where the two aforementioned tagged fish were taken, it seems reasonable to adhere to the assumption that the catch was essentially of Asian or western Alaskan origin.

Table 1.--Catch of chinook salmon in the foreign groundfish fisheries in the Bering Sea in 1979, by 3-month period, sex, and ocean age.

3-month Period	Sex	Ocean age	Total catch[a]	Proportion western Alaska[b]	Western Alaska catch
Jan.-Mar.	Male	.0	0	.90	0
		.1	1,143	"	1,029
		.2	21,487	"	19,338
		.3	5,482	"	4,934
		.4	616	"	554
		.5	29	"	26
	Female	.0	0	"	0
		.1	381	"	343
		.2	23,013	"	20,712
		.3	6,947	"	6,252
		.4	1,348	"	1,213
		.5	205	"	185
Apr.-Jun.	Male	.0	0	"	0
		.1	42	"	38
		.2	1,561	"	1,405
		.3	520	"	468
		.4	113	"	102
		.5	0	"	0
	Female	.0	0	"	0
		.1	56	"	50
		.2	1,125	"	1,013
		.3	563	"	507
		.4	169	"	152
		.5	42	"	38
Jul.-Sep.	Male	.0	0	"	0
		.1	68	"	61
		.2	1,332	"	1,199
		.3	307	"	276
		.4	0	"	0
		.5	0	"	0
	Female	.0	0	"	0
		.1	102	"	92
		.2	1,298	"	1,168
		.3	546	"	491
		.4	0	"	0
		.5	0	"	0
Oct.-Dec.	Male	.0	722	"	650
		.1	3,519	"	3,167
		.2	8,121	"	7,309
		.3	90	"	81
		.4	0	"	0
		.5	0	"	0
	Female	.0	902	"	812
		.1	3,158	"	2,842
		.2	13,716	"	12,344
		.3	1,444	"	1,300
		.4	0	"	0
		.5	0	"	0
TOTAL			100,167		90,151

a/ Total catch (number of fish) by 3-month period is derived from data reported by Nelson et al.(1980). The numbers of males and females in each ocean-age group were determined from data given by Rogers et al. (1982).
b/ Adapted from Major et al. 1977 (Figures 1a and 1b).

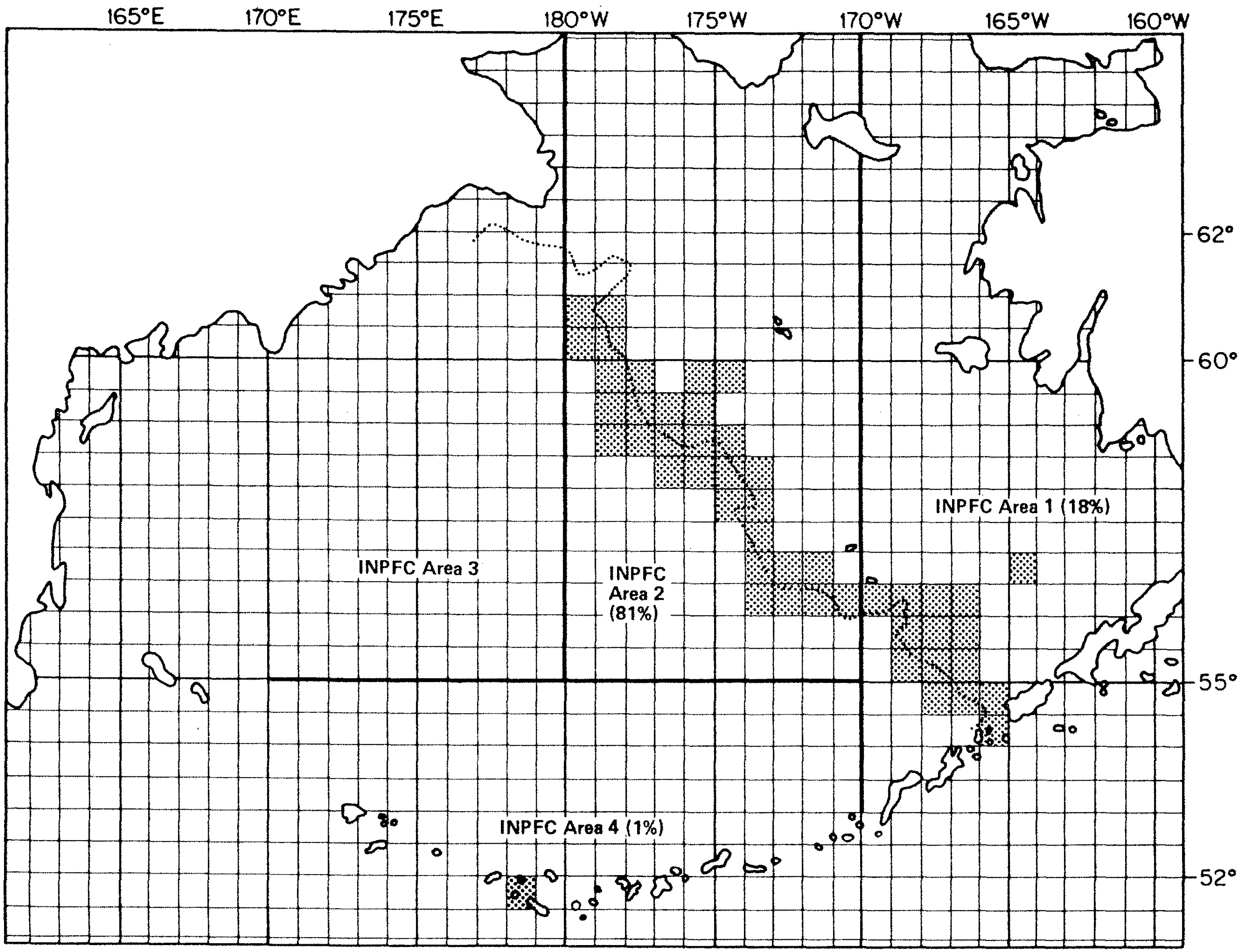

Figure 1.--Distribution of the catch of chinook salmon in the 1979 foreign groundfish fishery in the Bering Sea, by INPFC statistical area.

difference between the mean weight of a particular ocean-age and sex component of the high-seas catch and mean weight of the surviving members of that same component as they appear in the inshore catch 1 to 4 years later. Instantaneous growth rates (g) required for yield loss computations are estimated from the relationship:

$$g = (Ln\overline{W}_t - Ln\overline{W}_o)/t$$

where $Ln\overline{W}_t$ is the natural logarithm of the mean weight in kilograms of a particular ocean-age and sex group as they occur in the inshore fishery in mid-June, (t) months after their counterparts have been taken in the high-seas fishery. $Ln\overline{W}_o$ is the same statistic for the comparable group taken earlier in the high-seas fishery. The (g) values and the data from which they were computed are listed in Table 2. Growth (g) is on a per-month basis and (t) is the time elapsed from 15 February, 15 May, 15 August, or 15 November (the midpoints of the 3-month periods) to 15 June (the peak of the inshore season) in the same year or in the appropriate ensuing year.

Similarly, as with growth, there is little information on the natural mortality of western Alaska chinook salmon in the ocean. Researchers working with stocks of chinook salmon from other spawning areas, however, have used annual instantaneous rates from 0.1 to 0.69 (0.0083 to 0.0575 monthly) over varying periods of the oceanic life. Ricker (1980) uses an annual rate of 0.1 for fish aged 0.2 and older and asserts elsewhere (Ricker 1976) that 0.24 is probably somewhat too large. The value 0.2 (0.017 monthly) is used here.

Maturity schedule

Thus far, I have estimated the number of western Alaska chinook salmon taken by the foreign groundfish fishery in the Bering Sea in 1979 by 3-month period, sex, and ocean-age and assigned a growth rate and natural mortality rate to each category. However, because all fish in a particular category

Table 2.--Statistics for computing growth rate of chinook salmon during the period between the foreign groundfish and western Alaska fisheries.

Foreign groundfish fishery				Western Alaska fishery			
3-month Period	Sex	Ocean age	Mean wgt. (kg)[a]	Ocean age	Mean wgt. (kg)[b]	Elapsed time(mo)	Growth rate
Jan.-Mar.	Male	.1	0.49	.2	3.25	16	0.118
			0.49	.3	7.36	28	0.097
			0.49	.4	11.48	40	0.079
			0.49	.5	15.16	52	0.066
		.2	2.09	.2	3.25	4	0.108[c]
			2.09	.3	7.36	16	0.079
			2.09	.4	11.48	28	0.061
			2.09	.5	15.16	40	0.050
		.3	4.72	.3	7.36	4	0.108[c]
			4.72	.4	11.48	16	0.056
			4.72	.5	15.16	28	0.042
		.4	8.76	.4	11.48	4	0.068
			8.76	.5	15.16	16	0.034
		.5	17.50	.5	15.16	4	0.000[d]
	Female	.1	0.34	.2	3.29	16	0.142
			0.34	.3	8.54	28	0.115
			0.34	.4	11.37	40	0.088
			0.34	.5	13.39	52	0.071
		.2	1.85	.2	3.29	4	0.118[c]
			1.85	.3	8.54	16	0.096
			1.85	.4	11.37	28	0.065
			1.85	.5	13.39	40	0.049
		.3	4.39	.3	8.54	4	0.118[c]
			4.39	.4	11.37	16	0.059
			4.39	.5	13.39	28	0.040
		.4	8.90	.4	11.37	4	0.061
			8.90	.5	13.39	16	0.026
		.5	13.73	.5	13.39	4	0.000[d]
Apr.-Jun.	Male	.1	0.51	.2	3.25	13	0.142
			0.51	.3	7.36	25	0.107
			0.51	.4	11.48	37	0.084
			0.51	.5	15.16	49	0.069
		.2	2.10	.2	3.25	1	0.309
			2.10	.3	7.36	13	0.096
			2.10	.4	11.48	25	0.068
			2.10	.5	15.16	37	0.053
		.3	4.81	.3	7.36	1	0.309
			4.81	.4	11.48	13	0.067
			4.81	.5	15.16	25	0.046
		.4	9.46	.4	11.48	1	0.194
			9.46	.5	15.16	13	0.036
	Female	.1	0.58	.2	3.29	13	0.134
			0.58	.3	8.54	25	0.108
			0.58	.4	11.37	37	0.080
			0.58	.5	13.39	49	0.064

Table 2.--continued

Foreign groundfish fishery				Western Alaska fishery			
Period	Sex	Ocean age	Mean wgt. (kg)[a/]	Ocean age	Mean wgt. (kg)[b/]	Elapsed time(mo)	Growth rate
	Female	.2	2.21	.2	3.29	1	0.296[c/]
			2.21	.3	8.54	13	0.104
			2.21	.4	11.37	25	0.066
			2.21	.5	13.39	37	0.049
		.3	4.20	.3	8.54	1	0.296[c/]
			4.20	.4	11.37	13	0.077
			4.20	.5	13.39	25	0.046
		.4	9.81	.4	11.37	1	0.148
			9.81	.5	13.39	13	0.024
		.5	15.59	.5	13.39	1	0.000[d/]
Jul.-Sep.	Male	.1	1.98	.2	3.25	10	0.050
			1.98	.3	7.36	22	0.060
			1.98	.4	11.48	34	0.052
			1.98	.5	15.16	46	0.044
		.2	4.30	.3	7.36	10	0.054
			4.30	.4	11.48	22	0.045
			4.30	.5	15.16	34	0.037
		.3	6.18	.4	11.48	10	0.062
			6.18	.5	15.16	22	0.041
	Female	.1	2.20	.2	3.29	10	0.040
			2.20	.3	8.54	22	0.062
			2.20	.4	11.37	34	0.048
			2.20	.5	13.39	46	0.039
		.2	4.28	.3	8.54	10	0.069
			4.28	.4	11.37	22	0.044
			4.28	.5	13.39	34	0.034
		.3	6.36	.4	11.37	10	0.058
			6.36	.5	13.39	22	0.034
Oct.-Dec.	Male	.0	0.65	.2	3.25	19	0.085
			0.65	.3	7.36	31	0.078
			0.65	.4	11.48	43	0.067
			0.65	.5	15.16	55	0.057
		.1	1.89	.2	3.25	7	0.077
			1.89	.3	7.36	19	0.072
			1.89	.4	11.48	31	0.058
			1.89	.5	15.16	43	0.048
		.2	4.21	.3	7.36	7	0.080
			4.21	.4	11.48	19	0.053
			4.21	.5	15.16	31	0.041
		.3	7.22	.4	11.48	7	0.066
			7.22	.5	15.16	19	0.039
	Female	.0	0.47	.2	3.29	19	0.102
			0.47	.3	8.54	31	0.094
			0.47	.4	11.37	43	0.074
			0.47	.5	13.39	55	0.061

Table 2.--continued

Foreign groundfish fishery				Western Alaska fishery			
Period	Sex	Ocean age	Mean wgt. (kg)[a]	Ocean age	Mean wgt. (kg)[b]	Elapsed time(mo)	Growth rate
		.1	1.83	.2	3.29	7	0.084
			1.83	.3	8.54	19	0.081
			1.83	.4	11.37	31	0.059
			1.83	.5	13.39	43	0.046
		.2	4.11	.3	8.54	7	0.104
			4.11	.4	11.37	19	0.054
			4.11	.5	13.39	31	0.038
		.3	7.02	.4	11.37	7	0.069
			7.02	.5	13.39	19	0.034

a/ From data collected aboard foreign groundfish vessels by National Marine Fisheries Service observers, 1978, 1979, and 1981.

b/ All data originally collected by Alaska Department of Fish and Game. Data summaries for the Yukon River 1964-68 and 1981 and for the Kuskokwim River 1964-1968 are now on file at the Northwest and Alaska Fisheries Center. Bristol Bay data (1964-78) are from Meacham (1980). Data were weighted according to the following average run strengths compiled from Meacham and Arvey (1981): Yukon River 0.386, Kuskokwim River 0.263, and Bristol Bay 0.351. Lesser streams were ignored.

c/ The comparison of ocean and inshore weights can yield unrealistically high growth rates in situations where time elapsed (t) is small--specifically when the comparisons involve the Jan.-Mar. and Apr.-Jun. 3-month periods. Ricker (1976) noted the same thing in chum salmon data presented by LaLanne (1971), and attributed it to multiple elements that are likely present in the ocean sample--different stocks, for example. In this paper, growth rate is constrained in these few instances by not allowing it to exceed the growth rate observed in the ocean for .2 females, 0.999 of which are immature, over the same short periods (0.118 and 0.296 for the Jan.-Mar. and Apr.-Jun. 3-month periods, respectively. These constraints are adjusted slightly (0.108 and 0.309) to allow for differential growth between the males and females in the two 3-month periods.

d/ Minimum growth rate used in the model was 0.000.

are not destined to mature at the same time, it is also necessary to approximate the schedule according to which the fish at sea would have matured had they not been caught. This will ultimately permit growth and mortality to be balanced, one against the other, over the appropriate span of months and for the appropriate number of fish.

Maturity schedule of chinook taken at sea is derived from the ocean-age composition of the coastal catches of western Alaska chinook salmon. This is achieved by adjusting the observed inshore data backward in time to account for the mortalities that have occurred between the oceanic and coastal fisheries. Ideally, both natural mortality and fishing mortality should be taken into account in making such an adjustment (there being fishing mortalities associated with the foreign groundfish fishery itself and with the Japanese salmon mothership fishery). Because information on fishing mortality is lacking, however, adjustment here is for natural mortality only. The inability to correct for fishing mortality leads to overestimating the proportions of ocean-caught fish that are destined to mature at young ages and, conversely to underestimating proportions of fish that will mature at older ages. At least partially offsetting this bias is the effect of gillnet selectivity on the ocean-age composition of the inshore catch, which is the original basis for estimating the maturity schedule of fish taken at sea. Inshore gillnets tend to capture fewer younger-maturing fish and more older-maturing fish.

The initial ingredient in the computation of maturity schedule (the observed ocean-age composition of the mature catch) is from data collected in the Yukon, Kuskokwim, and Bristol Bay fishing regions--the major fishing regions of western Alaska. Using catch data from the individual regions as reported by Meacham and Arvey (1981) in conjunction with corresponding information on ocean-age composition (Meacham 1980) and sex ratio[3/], the ocean-age composition of chinook salmon caught in the commercial fisheries of western Alaska is estimated as follows:

	.2	.3	.4	.5
Males	0.115	0.397	0.425	0.063
Females	0.002	0.165	0.718	0.115

From the inshore data, maturity schedules are developed using the following expressions:

(1) maturity schedule (MS) of the .0s and .1s at sea during the third and fourth quarters and the .1s and .2s at sea during the first and second quarters (note that the .0s and .1s of the third and fourth quarters become the .1s and .2s of the first and second quarters of the following calendar year in that an additional winter annulus is assigned January 1):

$$MS = \frac{PP_i}{\Sigma PP_i}$$

$i = .2, .3, .4, \text{ or } .5$

(2) maturity schedule of the .2s at sea during the third and fourth quarters (.3s during the first and second quarters):

$$MS = \frac{PP_i}{\Sigma PP_i}$$

$i = .3, .4, \text{ or } .5$

3/ Unpublished data collected by Alaska Department of Fish and Game. Data now on file at the Northwest and Alaska Fisheries Center.

(3) maturity schedule of the .3s at sea during the third and fourth quarters (.4s during the first and second quarters):

$$MS = \frac{PP_i}{\Sigma PP_i}$$

$i = .4$ or $.5$

(4) maturity schedule of the .4s at sea during the third and fourth quarters (.5s during the first and second quarters):

$$MS = \frac{PP_i}{\Sigma PP_i}$$

$i = .5$

where $PP_i = \frac{OP_i}{e^{-qt_i}}$, PP_i being the proportion predicted to mature at ocean-age (i), OP_i the observed (inshore) proportion of ocean age (i), (q) the instantaneous natural mortality rate, and (t) the elapsed time in months. The maturity schedule is presented in Table 3 and the ultimate composition (number and weight) of western Alaska chinook salmon taken in the 1979 Bering Sea groundfish fishery by 3-month period, sex, ocean-age at capture and projected ocean age at return is shown in Table 4.

Yield loss

Following the approach of Parker (1963), the elements required for the calculation of yield loss are arranged in Table 5. Yield loss is calculated as follows:

$0.00015e^{1.616} + 0.00064e^{2.240} + 0.00085e^{2.480}$ etc.

for all of the remaining cells = 2.36.

Table 3.--Maturity schedule for various ocean-age groups of western Alaska chinook salmon taken in the foreign groundfish fishery.

3-month period	Average months to maturity	Males .0	Males .1	Males .2	Males .3	Males .4	Males .5	Females .0	Females .1	Females .2	Females .3	Females .4	Females .5
Jan.-Mar.	4	-	0.000	0.085	0.392	0.846	1.000	-	0.000	0.001	0.135	0.836	1.000
	16	-	0.085	0.358	0.515	0.154		-	0.001	0.135	0.723	0.164	
	28	-	0.358	0.472	0.093			-	0.135	0.722	0.142		
	40	-	0.472	0.085				-	0.722	0.142			
	52	-	0.085					-	0.142				
Apr.-Jun.	1	-	0.000	0.085	0.392	0.846	1.000	-	0.000	0.001	0.135	0.836	1.000
	13	-	0.085	0.358	0.515	0.154		-	0.001	0.135	0.723	0.164	
	25	-	0.358	0.472	0.093			-	0.135	0.722	0.142		
	37	-	0.472	0.085				-	0.722	0.142			
	49	-	0.085					-	0.142				
Jul.-Sep.	10	-	0.085	0.392	0.846	1.000	-	-	0.001	0.135	0.836	1.000	-
	22	-	0.358	0.515	0.154		-	-	0.135	0.723	0.164		-
	34	-	0.472	0.093			-	-	0.722	0.142			-
	46	-	0.085				-	-	0.142				-
	58	-					-	-					-
Oct.-Dec.	7	0.000	0.085	0.392	0.846	1.000	-	-	0.001	0.135	0.836	1.000	-
	19	0.085	0.358	0.515	0.154		-	-	0.135	0.723	0.164		-
	31	0.358	0.472	0.093			-	-	0.722	0.142			-
	43	0.472	0.085				-	-	0.142				-
	55	0.085					-	-					-

Table 4.--The number, mean weight, and total weight of western Alaska chinook salmon taken in the foreign groundfish fishery in the Bering Sea in 1979 by 3-month periods, sex, ocean-age at capture, ocean-age at maturity, and proportion of the total weight taken in each cell.

3-month period	Sex	Ocean age (foreign ground-fish fishery)	Ocean age at maturity	Mean weight (kg)	Number of fish[a/]	Total weight (kg)[a/]	Proportion of high-seas catch in weight
Jan.-Mar.	Male	.1	.2	0.49	87	43	0.00015
			.3	0.49	368	180	0.00064
			.4	0.49	486	238	0.00085
			.5	0.49	87	43	0.00015
		.2	.2	2.09	1,644	3,435	0.01227
			.3	2.09	6,923	14,469	0.05169
			.4	2.09	9,128	19,077	0.06815
			.5	2.09	1,644	3,435	0.01227
		.3	.3	4.72	1,934	9,129	0.03261
			.4	4.72	2,541	11,993	0.04285
			.5	4.72	459	2,166	0.00774
		.4	.4	8.76	469	4,108	0.01468
			.5	8.76	85	748	0.00267
		.5	.5	17.50	26	457	0.00163
	Female	.1	.2	0.34	0	0	0.00000
			.3	0.34	46	16	0.00006
			.4	0.34	248	84	0.00030
			.5	0.34	49	17	0.00006
		.2	.2	1.85	21	38	0.00014
			.3	1.85	2,796	5,173	0.01848
			.4	1.85	14,954	27,665	0.09884
			.5	1.85	2,941	5,441	0.01944
		.3	.3	4.39	844	3,705	0.01324
			.4	4.39	4,520	19,844	0.07089
			.5	4.39	888	3,898	0.01393
		.4	.4	8.90	1,014	9,027	0.03225
			.5	8.90	199	1,771	0.00633
		.5	.5	13.73	185	2,533	0.00905
Apr.-Jun.	Male	.1	.2	0.51	3	2	0.00001
			.3	0.51	14	7	0.00003
			.4	0.51	18	9	0.00003
			.5	0.51	3	2	0.00001
		.2	.2	2.10	119	251	0.00090
			.3	2.10	503	1,056	0.00377
			.4	2.10	663	1,393	0.00498
			.5	2.10	119	251	0.00090
		.3	.3	4.81	183	882	0.00315
			.4	4.81	241	1,159	0.00414
			.5	4.91	44	209	0.00075
		.4	.4	9.46	86	814	0.00291
			.5	9.46	16	148	0.00053
	Female	.1	.2	0.58	0	0	0.00000
			.3	0.58	7	4	0.00001
			.4	0.58	36	21	0.00008
			.5	0.58	7	4	0.00001
			.2	2.21	1	2	0.00001
			.3	2.21	137	302	0.00108
			.4	2.21	731	1,616	0.00577
			.5	2.21	144	318	0.00114

Table 4.--continued

3-month period	Sex	Ocean age (foreign groundfish fishery)	Ocean age at maturity	Mean weight (kg)	Number of fish[a/]	Total weight (kg)[a/]	Proportion of high-seas catch in weight
		.3	.3	4.20	68	287	.00103
			.4	4.20	366	1,539	.00550
			.5	4.20	72	302	.00108
		.4	.4	9.81	127	1,247	.00446
			.5	9.81	25	245	.00088
		.5	.5	15.59	38	589	.00210
Jul.-Sep.	Male	.1	.2	1.98	5	10	.00004
			.3	1.98	22	43	.00015
			.4	1.98	29	57	.00020
			.5	1.98	5	10	.00004
		.2	.3	4.30	470	2,021	.00722
			.4	4.30	617	2,655	.00949
			.5	4.30	111	479	.00171
		.3	.4	6.18	234	1,445	.00516
			.5	6.18	43	263	.00094
	Female	.1	.2	2.20	0	0	.00000
			.3	2.20	12	27	.00010
			.4	2.20	66	146	.00052
			.5	2.20	13	29	.00010
		.2	.3	4.28	158	675	.00241
			.4	4.28	845	3,615	.01291
			.5	4.28	166	710	.00254
		.3	.4	6.36	411	2,613	.00934
			.5	6.36	81	513	.00183
Oct.-Dec.	Male	.0	.2	0.65	55	36	.00013
			.3	0.65	233	151	.00054
			.4	0.65	307	199	.00071
			.5	0.65	55	36	.00013
		.1	.2	1.89	269	509	.00182
			.3	1.89	1,134	2,143	.00766
			.4	1.89	1,495	2,825	.01009
			.5	1.89	269	509	.00182
		.2	.3	4.21	2,865	12,062	.04309
			.4	4.21	3,764	15,847	.05662
			.5	4.21	680	2,862	.01022
		.3	.4	7.22	69	995	.00177
			.5	7.22	12	90	.00032
	Female	.0	.2	0.47	1	0	.00000
			.3	0.47	110	52	.00019
			.4	0.47	586	275	.00098
			.5	0.47	115	54	.00019
		.1	.2	1.83	3	5	.00002
			.3	1.83	384	702	.00251
			.4	1.83	2,052	3,756	.01342
			.5	1.83	404	739	.00264
		.2	.3	4.11	1,666	6,849	.02447
			.4	4.11	8,925	36,682	.13105
			.5	4.11	1,753	7,204	.02574
		.3	.4	7.02	1,086	7,627	.02725
			.5	7.02	213	1,496	.00534
	Total				90,150	279,908	

a/ Rounded to the nearest whole number here; carried to 5 decimal places in the calculation of the proportion of each category in the total high-seas catch.

Table 5.--Information for calculating yield-loss of western Alaska chinook salmon taken in the 1979 foreign groundfish fishery in the Bering Sea.

A	B	C	D	E	F	G	H	I	J
3-month period	Sex	Ocean-age (foreign ground-fish fishery)	Ocean-age at maturity	Time (mo)	Monthly instantaneous rate of change: Growth	Mortality	Mass(F-G)	Total change in mass (E x H)	Weighting factor
Jan.-Mar.	Male	.1	.2	16	0.118	0.017	0.101	1.616	0.00015
			.3	28	0.097	0.017	0.080	2.240	0.00064
			.4	40	0.079	0.017	0.062	2.480	0.00085
			.5	52	0.066	0.017	0.049	2.548	0.00015
		.2	.2	4	0.108	0.017	0.091	0.364	0.01227
			.3	16	0.079	0.017	0.062	0.992	0.05169
			.4	28	0.061	0.017	0.044	1.232	0.06815
			.5	40	0.050	0.017	0.033	1.320	0.01227
		.3	.3	4	0.108	0.017	0.091	0.364	0.03261
			.4	16	0.056	0.017	0.039	0.624	0.04285
			.5	28	0.042	0.017	0.025	0.700	0.00774
		.4	.4	4	0.068	0.017	0.051	0.204	0.01468
			.5	16	0.034	0.017	0.017	0.272	0.00267
		.5	.5	4	0.000	0.017	-0.017	-0.068	0.00163
	Female	.1	.2	16	0.142	0.017	0.125	2.000	0.00000
			.3	28	0.115	0.017	0.098	2.744	0.00006
			.4	40	0.088	0.017	0.071	2.840	0.00030
			.5	52	0.071	0.017	0.054	2.808	0.00006
		.2	.2	4	0.118	0.017	0.101	0.404	0.00014
			.3	16	0.096	0.017	0.079	1.264	0.01848
			.4	28	0.065	0.017	0.048	1.344	0.09884
			.5	40	0.049	0.017	0.032	1.220	0.01944
		.3	.3	4	0.118	0.017	0.101	0.404	0.01324
			.4	16	0.059	0.017	0.042	0.672	0.07089
			.5	28	0.040	0.017	0.023	0.644	0.01393
		.4	.4	4	0.061	0.017	0.044	0.244	0.03225
			.5	16	0.026	0.017	0.009	0.144	0.00633
		.5	.5	4	0.000	0.017	-0.017	-0.068	0.00905
Apr.-Jun.	Male	.1	.2	13	0.142	0.017	0.125	1.625	0.00001
			.3	25	0.107	0.017	0.090	2.250	0.00003
			.4	37	0.084	0.017	0.062	2.479	0.00003
			.5	49	0.069	0.017	0.052	2.548	0.00001
		.2	.2	1	0.309	0.017	0.292	0.292	0.00090
			.3	13	0.096	0.017	0.079	1.027	0.00377
			.4	25	0.068	0.017	0.051	1.275	0.00498
			.5	37	0.053	0.017	0.036	1.332	0.00090
		.3	.3	1	0.309	0.017	0.292	0.292	0.00315
			.4	13	0.067	0.017	0.050	0.650	0.00414
			.5	25	0.046	0.017	0.029	0.725	0.00075
		.4	.4	1	0.194	0.017	0.177	0.177	0.00291
			.5	13	0.036	0.017	0.019	0.247	0.00053
	Female	.1	.2	13	0.134	0.017	0.117	1.521	0.00000
			.3	25	0.108	0.017	0.091	2.275	0.00001
			.4	37	0.080	0.017	0.063	2.331	0.00008
			.5	49	0.064	0.017	0.047	2.303	0.00001
		.2	.2	1	0.296	0.017	0.279	0.279	0.00001
			.3	13	0.104	0.017	0.087	1.131	0.00108
			.4	25	0.066	0.017	0.049	1.225	0.00577
			.5	37	0.049	0.017	0.032	1.184	0.00114

Table 5.--continued.

A	B	C	D	E	F	G	H	I	J
3-month period	Sex	Ocean-age (foreign groundfish fishery)	Ocean-age at maturity	Time (mo)	Monthly instantaneous rate of change: Growth	Mortality	Mass (F-G)	Total change in mass (E x H)	Weighting factor
		.3	.3	1	0.296	0.017	0.279	0.279	.00103
			.4	13	0.077	0.017	0.060	0.780	.00550
			.5	25	0.046	0.017	0.029	0.725	.00108
		.4	.4	1	0.148	0.017	0.131	0.131	.00446
			.5	13	0.024	0 017	0.007	0.091	.00088
		.5	.5	1	0.000	0.017	-0.017	-0.017	.00210
Jul.-Sep.	Male	.1	.2	10	0.050	0.017	0.033	0.330	.00004
			.3	22	0.060	0.017	0.043	0.946	.00015
			.4	34	0.052	0.018	0.035	1.190	.00020
			.5	46	0.044	0.017	0.027	1.242	.00004
		.2	.3	10	0.054	0.017	0.037	0.370	.00722
			.4	22	0.045	0.017	0.028	0.616	.00949
			.5	34	0.037	0.017	0.020	0.680	.00171
		.3	.4	10	0.062	0.017	0.045	0.620	.00516
			.5	22	0.041	0.017	0.024	0.528	.00094
	Female	.1	.2	10	0.040	0.017	0.023	0.230	.00000
			.3	22	0.062	0.017	0.045	0.990	.00010
			.4	34	0.048	0.017	0.031	1.054	.00052
			.5	46	0.039	0.017	0.022	1.012	.00010
		.2	.3	10	0.069	0.017	0.052	0.502	.00241
			.4	22	0.044	0.017	0.027	0.594	.01291
			.5	34	0.034	0.017	0.017	0.578	.00254
		.3	.4	10	0.058	0.017	0.041	0.410	.00934
			.5	22	0.034	0.017	0.017	0.374	.00183
Oct.-Dec.	Male	.0	.2	19	0.085	0.017	0.068	1.292	.00013
			.3	31	0.078	0.017	0.061	1.891	.00054
			.4	43	0.067	0.017	0.050	2.150	.00071
			.5	55	0.057	0.017	0.040	2.200	.00013
		.1	.2	7	0.077	0.017	0.060	0.420	.00182
			.3	19	0.072	0.017	0.055	1.045	.00766
			.4	31	0.058	0.017	0.041	1.271	.01009
			.5	43	0.048	0.017	0.031	1.333	.00182
		.2	.3	7	0.080	0.017	0.063	0.441	.04309
			.4	19	0.053	0.017	0.036	0.684	.05662
			.5	31	0.041	0.017	0.024	0.744	.01022
		.3	.4	7	0.066	0.017	0.049	0.343	.00177
			.5	19	0.039	0.017	0.022	0.418	.00032
	Female	.0	.2	19	0.102	0.017	0.085	1.615	.00000
			.3	31	0.094	0.017	0.077	2.387	.00019
			.4	43	0.074	0.017	0.057	2.451	.00098
			.5	55	0.061	0.017	0.044	2.420	.00019
		.1	.2	7	0.084	0.017	0.067	0.469	.00002
			.3	19	0.081	0.017	0.064	1.215	.00251
			.4	31	0.059	0.017	0.042	1.302	.01342
			.5	43	0.046	0.017	0.029	1.247	.00264
		.2	.3	7	0.104	0.017	0.087	0.609	.02447
			.4	19	0.054	0.017	0.037	0.703	.13105
			.5	31	0.038	0.017	0.021	0.651	.02574
		.3	.4	7	0.069	0.017	0.042	0.294	.02725
			.5	19	0.034	0.017	0.017	0.323	.00534

Thus, the weight of the surviving fish as they reach the coast is 2.36 times the weight of the catch of western Alaska chinook salmon in the foreign groundfish fishery. Expressed in terms of total weight, potential yield loss is 2.36 x 279,908 kg (Table 4) = 660,583 kg, assuming that the taking of western Alaska chinook salmon on the high seas was eliminated and assuming the existence of an inshore fishery capable of catching all fish available to it. More likely, yield loss would be some fraction of the potential, depending on the fraction of the total run harvested.

It is instructive at this point to compare the yield-loss ratio computed here with other yield-loss ratios reported for Pacific salmon. To do this, it is necessary to temporarily set aside the effects of noncatch mortality associated with gillnets -- a factor that inflated the yield-loss ratios in all earlier studies. Thus adjusted, the yield-loss ratios are as follows:

No.	Yield-loss ratio	Source	Fishery
1.	3.26	Major 1982	Western Alaska chinook salmon, Japanese mothership fishery, 1980
2.	2.36	Present study	Western Alaska chinook salmon, foreign groundfish fishery, Bering Sea, 1979
3.	1.98	Adapted from Fredin 1964	Karluk River .4 sockeye salmon "pelagic fishery"
4.	1.89	Adapted from Ricker 1964	Chum salmon (ocean age .3), "high-seas fishery"
5.	1.68	Adapted from Parker 1963	Asian sockeye salmon, "high-seas fishery"

It is noteworthy that the yield loss ratio is higher for chinook salmon taken on the high seas, in either the Japanese mothership fishery or the foreign groundfish fishery, than for other species of Pacific salmon. In the

Japanese mothership gillnet fishery, this occurs because chinook are recruited to the fishery at a relatively young ocean age and small size. Chinook taken by the gillnets in the year in question (1980) were .1, .2, and .3 ocean-age fish -- some up to 3 years from maturity, whereas the other species are taken only 1 year from maturity. Exponential changes in population mass thus become large very quickly when protracted over an additional year or two at sea.

It is also in order to compare the yield-loss ratios for chinook salmon taken in the high-seas gillnet and trawl fisheries. The gillnets fished by the Japanese mothership fleet are very selective for small and medium-sized .2 chinook and therefore tend to take only the very largest .1s and fewer of the larger .2s and the .3s (Major et al. 1978). Trawls, on the other hand, are not as size selective as gillnets, if at all, with respect to salmon, and consequently take chinook salmon as they occur at ocean ages .1, .2, .3, and even .4 and .5. That the larger .2s, the .3s, and even .4s and .5s (fish closer to maturity) are present among the trawl-caught chinook salmon explains why yield loss computed for the groundfish fishery (2.36) is less than that for the mothership gillnet fishery (3.26). Other species of salmon, it should be pointed out, are not taken in meaningful numbers in bottom trawls and interspecies comparisons of yield loss associated with this type of fishery are therefore not in question.

Finally, it should be bourne in mind that the yield-loss ratio computed for chinook salmon, because of the presence of multiple ocean-age groups, will be a dynamic statistic -- varying from year to year as the ocean-age composition of the catch varies. Thus, when older and larger chinook salmon predominate, yield loss will be lower, and when younger and smaller abound, yield loss will be higher. This is particularly true for the trawl fishery which tends to take the ocean-age groups as they occur rather than the mothership gillnet fishery which will always tend to select a disproportionate number of .2s regardless of the ocean-age composition of the population.

SENSITIVITY ANALYSIS

Inquiries such as this, dependent as they are on data collected for other purposes by other agencies, are susceptible to more than ordinary error. Examples of potential error were originally discussed in the earlier paper dealing with the 1980 Japanese mothership fishery (Major 1982) and will not be repeated here. Rather, the sensitivity analysis employed in the earlier study is used again here to estimate the relative impact of errors surrounding growth, natural mortality, and maturity schedule. This is achieved by perturbing the variables one at a time and then measuring the adjusted output of the model in terms of the output obtained in a base run. Results are expressed as:

$$\text{Relative sensitivity} = \frac{\text{percent change in output}}{\text{percent change in the variable.}}$$

The advantage of the relative sensitivity measurement is that it minimizes the effect of different orders of magnitude which may exist among the tested variables and the outputs.

For the sensitivity analysis, growth is allowed to vary by $\pm$ 10% and natural mortality by $\pm$ 50% (there being even less certainty about the natural mortality rate than the growth rate). Maturity schedule is examined in terms of the average ocean age at return projected for .0, .1, .2, .3, .4, and .5 fish in the high-seas catch. Maturity schedules are, in turn, based on the ocean-age composition of .2, .3, .4, and .5 fish in the historical inshore catch, 1964-78. Three such ocean-age compositions were used in the sensitivity analysis. The first (the 1964-78 average) has already been described and employed in the text run of the model. Average ocean age at return under this condition was 3.84 years. Ocean-age compositions were also selected which would minimize and maximize average ocean age at return. The resultant values, 3.62 and 3.98 years, respectively, are compared in the tests to the average age, 3.84 years.

The results of the sensitivity analysis are summarized in Table 6. Of the three variables examined, growth is clearly the most powerful element in the model. A decrease in growth rate causes an even larger decrease in output, and an increase in growth rate brings about an even larger increase in output.

Maturity schedule exerts moderate influence on estimates of yield loss. When the fish taken on the high seas are scheduled to return at younger ocean age, yield loss decreases, and when they are scheduled to return at older ocean age, yield loss increases.

Natural mortality rate is the least important of the four variables tested to measure their effect on yield loss ratio. The relationship is negative; as natural mortality increases, model output decreases and when natural mortality decreases, model output increases. A change in natural mortality rate exerts offsetting influences within the model. An increase in natural mortality would, for example, result in fewer fish reaching maturity (tending to reduce yield loss); but by using the same increased mortality rate in the calculation of maturity schedule, the maturing fish, although fewer in number would be older (tending to increase yield loss). As a result of these offsetting influences, a change in natural mortality rate does not bring about as large a change in output as a comparable change in growth rate, even though both variables are exponential. A 50% change in the natural

Table 6.--Sensitivity analysis of growth, natural mortality, and maturity schedule -- inputs in the model to compute yield loss of western Alaska chinook salmon resulting from the 1979 foreign groundfish fishery in the Bering Sea.

Variable	Loss value	Test value	Output (yield loss)	Percent change Variable	Percent change Output	Relative sensitivity
Growth	1.00		2.36			
(annual		0.90	2.07	-10.00	-12.29	1.23
instantaneous		1.10	2.69	10.00	13.98	1.40
rate)[a]						
Natural mortality	0.20		2.36			
(annual		0.10	2.81	-50.00	19.07	-0.38
instantaneous		0.30	1.98	50.00	-16.10	-0.32
rate)						
Maturity schedule	3.84		2.36			
(average projected		3.62	2.27	-5.73	-3.81	0.66
ocean age at return)		3.98	2.40	3.65	1.69	0.46

a/ Fish in each of the 99 cells have their own unique rate of growth. For the sensitivity analysis, the rate of growth for each cell used in the standard model run was assigned a value of 1.00 and allowed to vary by 10% in either direction; hence the values 0.90 and 1.10.

mortality rate (Table 6) would bring about a smaller (15% to 20%) change in output, depending on the direction of the change.

If all three variables are taken to their extreme simultaneously, potential yield loss expressed as a ratio would vary from 1.73 to 3.33, with all but the lowest values exceeding those computed earlier for other species of Pacific salmon, save chinook salmon taken in gillnets.

Unexamined to this point is the proportion of the catch that is initially identified as western Alaskan. This variable does not affect yield loss expressed as a ratio, but it has direct one-to-one effect when yield loss is expressed in terms of weight. When the proporiton of western Alaska chinook salmon is set at 80% and 100% (to bracket the 90% value used in the text run of the model) and used in conjunction with the minimum and maximum ratios used above--1.73 and 3.33, respectively, it is determined that the potential yield loss in terms of weight ranges from 429,510 to 1,036,958 kg, thus providing some bounds to the estimate of 660,583 kg obtained in the base run of the model.

From the foregoing analysis, growth rate, the identification of western Alaska fish, maturity schedule, and natural mortality rate all emerge as variables that exert substantial influence on estimates of yield loss of western Alaska chinook salmon resulting from high-seas trawling. Aside from the work being done at the Fisheries Research Institute, University of Washington, to identify the origin of chinook salmon taken in the groundfish fishery (Rogers et al. 1982; Myers 1982), the other elements in the model, the growth, mortality, and maturity schedule of chinook salmon on the high seas remain unexamined and are thus fertile topics for study.

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