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Cohort Analysis of Catch Data on Pacific Herring in the Eastern Bering Sea, 1959-81

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COHORT ANALYSIS OF CATCH DATA ON PACIFIC HERRING IN THE EASTERN BERING SEA, 1959-81

by

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ABSTRACT

Cohort analysis (Pope 1972) was used to examine the abundance of Pacific herring in the eastern Bering Sea between 1959 and 1981. The results of the analysis show that herring abundance declined through the 1960's, going from a high of 1.7 million t in 1962 to 153 thousand t in 1973. Since 1973 herring abundance has been increasing.

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INTRODUCTION

Pacific herring (Clupea harengus pallasi) of the eastern Bering Sea have been exploited since 1959, first in a winter food fishery by Japanese and Soviet fisheries and in more recent years by a U.S. spring-summer roe fishery. Very little quantitative fishery or research data is available prior to the establishment of the United States fishery conservation zone. An unpublished manuscript, Naumenko (1979), was presented by Soviet scientists at the 1979 U.S.-U.S.S.R. bilateral scientific discussions which contained data and analyses based on Soviet fisheries from 1960-78. He determined that the average spawning biomass during 1961-78 was 289 thousand metric tons (t) and ranged between 133 and 445 thousand t.

Naumenko's analysis cannot be totally validated, as some of his procedures and assumptions were not clearly defined and some of the basic data used in the analysis were omitted. However, data in his paper can be used to examine the history of eastern Bering Sea herring. This report summarizes the results of a cohort analysis (Pope 1972) utilizing Soviet and Alaska Department of Fish and Game (ADFG) age composition data.

METHODS

Cohort analysis estimates the population abundance of a year class in preceding years using catch data and natural mortality (M) estimates. The catch data used are those contained in the Bering Chuckchi-Sea herring fishery management plan (North Pacific Fishery Management Council 1982). Catches from 1959-77 were converted from weight (t) to numbers (Table 1) by dividing the catch by the estimated annual mean weight. The estimated total number of herring in the catch were then apportioned to age using the catch age composition (Table 2). Annual mean weights were estimated by multiplying the catch

Table 1.--Catch (number of fish) of Pacific herring in the Bering-Chukchi Sea, 1959-81.

Age	1959	1960	1961	1962	1963	1964
1	47,891	47,545	108,951	2,057,834	0	0
2	8,362,821	1,079,208	384,434	23,608,897	687,728	0
3	23,666,215	15,449,709	6,022,799	19,272,569	12,894,903	1,325,105
4	853,349	24,651,374	60,868,711	19,272,569	12,894,903	3,533,613
5	5,802,774	3,351,224	32,805,031	93,231,052	12,894,903	3,533,613
6	7,168,132	7,384,052	13,198,900	52,276,844	91,639,776	1,987,657
7	3,072,056	2,896,820	6,535,377	16,863,498	22,351,165	24,072,737
8	6,485,453	1,249,609	4,356,918	8,431,749	12,894,903	5,521,270
9	853,349	624,804	2,691,038	4,577,235	4,126,369	1,766,806
10	0	56,800	1,153,302	963,628	1,547,389	883,404

Age	1965	1966	1967	1968	1969	1970
1	0	0	302,777	2,248,175	0	0
2	1,223,514	0	0	15,278,441	134,542,527	853,271
3	3,460,796	265,294	1,349,252	31,066,163	49,118,700	165,961,211
4	3,495,754	4,539,471	1,686,565	41,761,072	13,881,372	78,927,569
5	4,789,183	1,709,670	16,865,651	35,649,696	13,881,372	24,318,223
6	3,950,202	5,954,371	4,047,757	198,619,733	40,042,419	22,185,046
7	6,362,272	2,269,736	3,035,817	27,501,194	163,373,068	29,437,850
8	11,326,241	4,539,471	5,059,695	28,519,756	30,966,137	62,715,419
9	279,660	8,489,400	13,155,208	30,556,882	26,161,047	13,225,701
10	69,915	1,709,670	19,226,842	67,734,422	20,822,058	15,358,878

Age	1971	1972	1973	1974	1975	1976
1	0	197,872	467,597	2,238,725	3,357,313	139,401
2	8,545,044	3,537,149	18,033,162	34,649,641	4,894,121	49,741,422
3	14,117,898	47,397,789	27,217,755	10,903,733	25,262,305	31,088,389
4	144,522,694	58,245,045	18,145,170	16,719,057	1,583,392	87,738,342
5	28,235,796	123,092,767	8,736,563	13,690,243	4,822,150	345,426
6	30,836,462	2,122,289	37,970,448	14,538,311	11,875,442	172,713
7	21,176,847	0	1,120,072	23,382,450	8,204,851	345,426
8	33,437,127	471,620	224,014	3,149,968	11,227,691	518,140
9	69,103,396	235,810	0	969,220	143,945	2,417,986
10	7,430,472	471,620	0	363,458	0	172,713

Age	1977	1978	1979	1980	1981
1	0	0	0	0	0
2	84,482	0	0	0	0
3	41,903,142	4,542,907	15,805,743	729,663	502,326
4	8,110,286	64,274,334	6,743,111	5,033,342	43,952,459
5	29,061,856	23,825,255	35,120,822	1,731,548	11,345,412
6	422,411	6,773,218	14,955,502	50,901,386	1,497,692
7	591,375	952,748	6,136,127	32,529,100	13,829,491
8	1,098,268	813,551	421,698	8,197,040	4,966,154
9	675,857	117,090	536,962	1,782,780	2,931,157
10	2,534,464	0	0	0	0

Table 2.--Catch-age composition, and mean weights for eastern Bering Sea Pacific herring, 1959-81.

Year (April-March)	Age composition numbers of fish (%)												Mean wt. (g)	Catch (t)
	1	2	3	4	5	6	7	8	9	10	11	12		
1959	0.001	0.147	0.416	0.015	0.102	0.126	0.054	0.114	0.015	0.000	0.003	0.006	209	10,000
1960	0.001	0.019	0.272	0.434	0.059	0.130	0.051	0.022	0.011	0.001	0.000	0.000	206	9,800
1961	0.001	0.003	0.047	0.475	0.256	0.103	0.051	0.034	0.021	0.009	0.000	0.000	224	24,450
1962	0.010	0.098	0.080	0.080	0.387	0.217	0.070	0.035	0.019	0.004	0.000	0.000	229	47,060
1963	0.000	0.004	0.075	0.075	0.075	0.533	0.130	0.075	0.024	0.009	0.000	0.000	260	38,950
1964	0.000	0.000	0.030	0.080	0.080	0.045	0.545	0.125	0.040	0.020	0.030	0.005	291	11,380
1965	0.000	0.035	0.099	0.100	0.137	0.113	0.182	0.324	0.008	0.002	0.000	0.000	266	8,117
1966	0.000	0.000	0.009	0.154	0.058	0.202	0.077	0.154	0.288	0.058	0.000	0.000	299	7,831
1967	0.005	0.000	0.020	0.025	0.250	0.060	0.045	0.075	0.195	0.285	0.030	0.011	321	19,438
1968	0.005	0.030	0.061	0.082	0.070	0.390	0.054	0.056	0.060	0.133	0.045	0.013	283	127,137
1969	0.000	0.252	0.092	0.026	0.026	0.075	0.306	0.058	0.049	0.039	0.070	0.007	254	118,123
1970	0.000	0.002	0.389	0.185	0.057	0.052	0.069	0.147	0.031	0.036	0.018	0.014	234	85,979
1971	0.000	0.023	0.038	0.389	0.076	0.083	0.057	0.090	0.186	0.020	0.030	0.008	263	85,310
1972	0.001	0.015	0.201	0.247	0.522	0.009	0.000	0.002	0.001	0.002	0.000	0.000	207	40,905
1973	0.005	0.161	0.243	0.162	0.078	0.339	0.010	0.002	0.000	0.000	0.000	0.000	203	18,985
1974	0.022	0.286	0.090	0.138	0.113	0.120	0.193	0.026	0.008	0.003	0.000	0.000	208	21,153
1975	0.055	0.068	0.351	0.022	0.067	0.165	0.114	0.156	0.002	0.000	0.000	0.000	220	13,424
1976	0.001	0.288	0.180	0.508	0.002	0.001	0.002	0.003	0.014	0.001	0.000	0.000	174	24,222
1977	0.000	0.001	0.496	0.096	0.344	0.005	0.007	0.013	0.008	0.030	0.000	0.000	201	14,144
1978	0.000	0.000	0.045	0.635	0.235	0.067	0.009	0.008	0.001	0.000	0.000	0.000	209	15,242
1979	0.000	0.000	0.198	0.085	0.441	0.188	0.077	0.005	0.007	0.000	0.000	0.000	226	15,074
1980	0.000	0.000	0.007	0.050	0.017	0.504	0.322	0.081	0.018	0.000	0.000	0.000	276	26,761
1981	0.000	0.000	0.006	0.556	0.144	0.019	0.175	0.063	0.037	0.000	0.000	0.000	234	17,652
Mean	0.005	0.062	0.150	0.201	0.156	0.154	0.113	0.073	0.045	0.028	0.010	0.003		

age distribution by age specific weights derived from a regression of weights collected during the 1978-81 roe fisheries on age (Clark 1978; McBride et al. 1981)(Figure 1). Catches from 1978 to 1981 were distributed using age composition and weight data reported by Clark (1978), McBride et al. (1981), and unpublished ADFG data reports.

The second set of input data, natural mortality rates (M), are not well defined for eastern Bering Sea herring. An approximation of average natural mortality can be obtained using the Alverson and Carney (1975) procedure which estimates M by:

$$tmb = (1/k)\ \ln\ [(M + 3k)/M]$$

$$tmb = 0.25 \text{ maximum observed age}$$

where k is the Von Bertalanffy growth coefficient.

Using k = 0.35 computed from back calculated length-at-age data (Shaboneev 1965) obtained when stocks were near virgin levels, and maximum observed age = 15 years, the estimate of average instantaneous natural mortality = 0.39.

Regression analysis of catch composition data (x = age, y = 1n [catch age xl) resulted in a total instantaneous mortality (z) estimate of 0.57 (r^2=.90) for ages 4-12 during 1959-81. Subtracting the estimated instantaneous natural mortality rate (.39) from these estimates indicates that fishing mortality was 0.18 or 32% of total mortality in fully recruited ages.

Age specific estimates of Z were estimated from the mean catch composition of ages 4-12 as the 1n (N_i/N_{i-l}). The estimated Z for age 5 was extremely low because of its inordinately high catch proportion in 1980 due to failure of younger fish to enter the fishery in that year. An exponential regression was fitted to the age specific Z estimates following the adjustment for age 5 (Figure 2). Age specific natural mortalities were

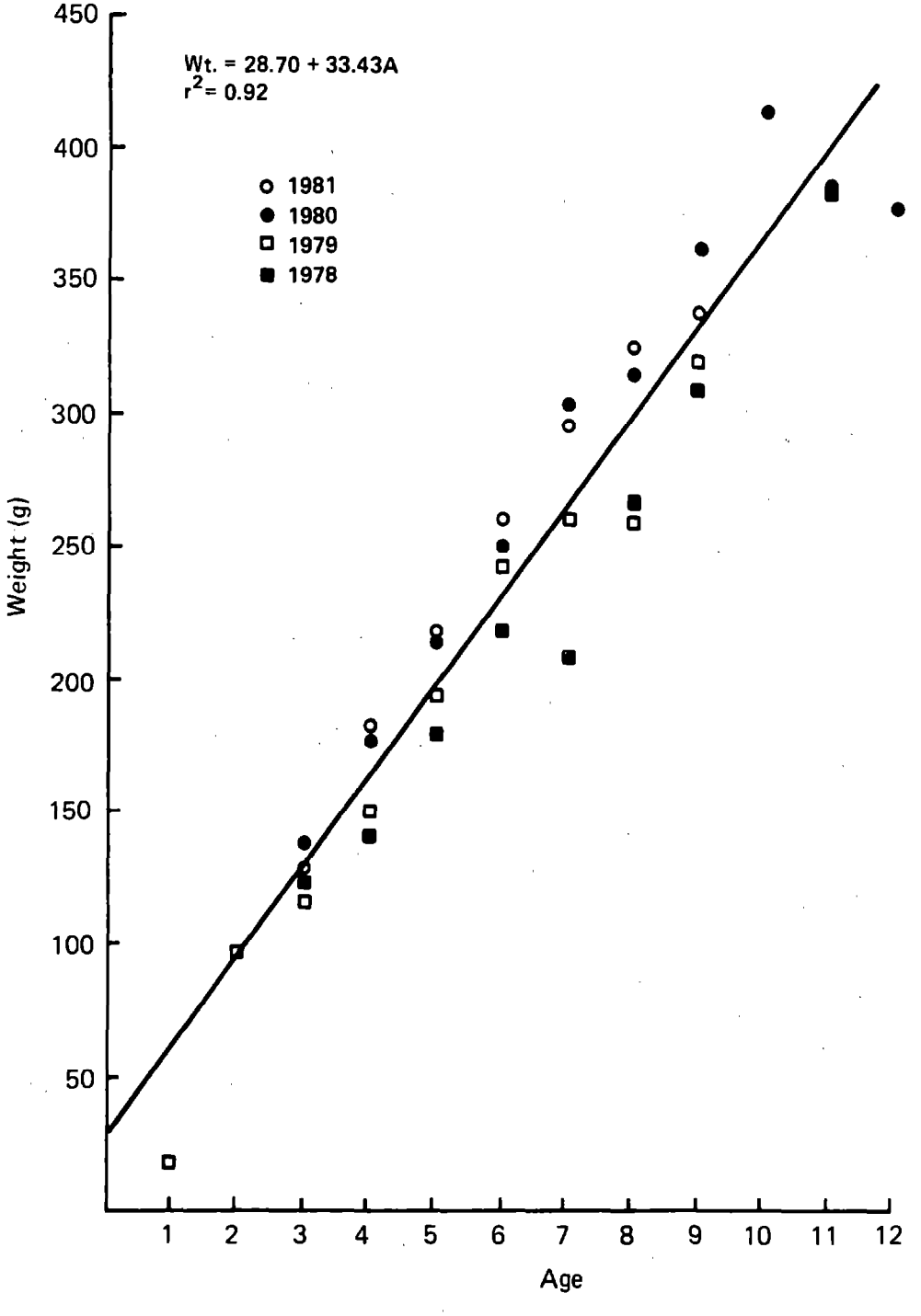

Figure 1. --weight-at-age relationship derived from variable mesh gillnet samples of Pacific herring collected by Alaska Department of Fish and Game in the Togiak area of Bristol Bay during the spawning period in 1978-81.

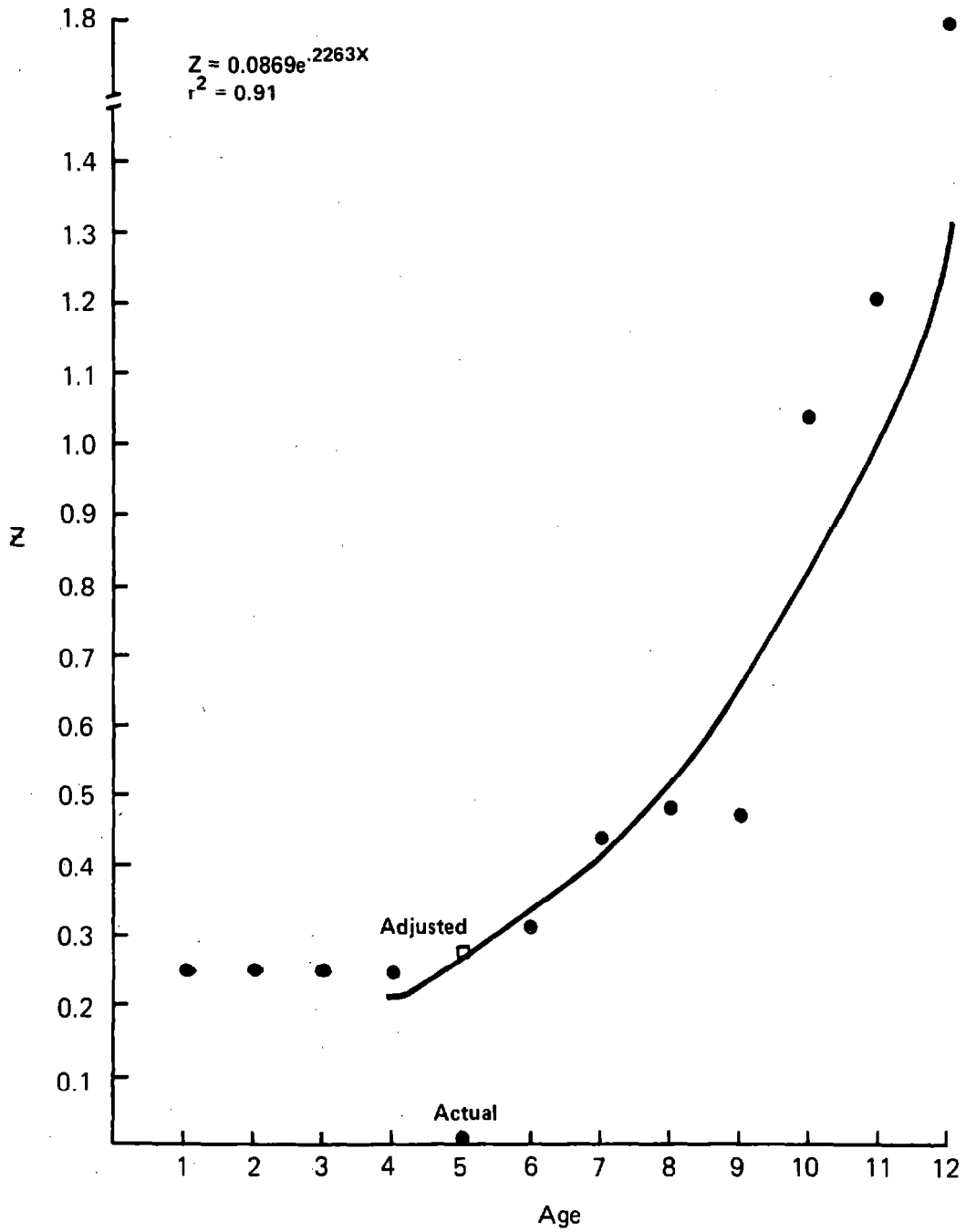

Figure 2.--Age specific estimates of total mortality (Z) derived from the 1959-81 catch of Pacific herring in the eastern Bering Sea. Rates for ages l-3 are assumed rates.

estimated from fitted total mortality by assuming that fishing mortality accounted for 32% of total mortality during the period of analysis. For ages l-2, fishing mortality (F) was assumed to be zero and M for ages 1-3 was assumed equal to 0.25. Decaying a cohort by these rates shows maximum cohort biomass at age 5 (Table 3). A maximum at age 5 indicates that the estimated rates are too low at least for ages 1-4, since cohort biomass peaks at age 3 and catches are observed to peak at age 4 (Naumenko 1979; North Pacific Fishery Management Council 1982).

To run a cohort analysis, estimates of F must be supplied for the oldest age of a year-class (Table 4). This involves all ages in the last year and the oldest age in prior years. For the last year, 1981, initial terminal F values of 0.10 were used for all ages. In subsequent runs, F values were adjusted until the age distribution of the population estimate equalled the age distribution of weighted 1981 ADFG test fish samples. The weighted age distribution was derived by weighting the distribution of each sample (spawning area) by sample size. The weighted test fish samples were further modified by maturity rates (1959-77 averages) to adjust for fish not recruited to the roe fishery. The estimate of F for the last age of a year class in the catch was set equal to the value computed for the immediate younger age in the same year based on the assumption of equal catchability.

The actual cohort analysis is number based and results are in numbers of fish. However, to increase the comprehension of the output, estimates in numbers were converted to biomass using regression derived weights (Figure 1). Spawning biomasses were also calculated by multiplying the biomass at age in each year by the corresponding maturity rate reported by Naumenko (1979)(Table 5).

Table 3.--Age specific estimates of total mortality (Z), natural mortality (M), and the distribution of numbers (N) and biomass of a cohort of Pacific herring decayed by these rates of natural mortality.

	Z[1/] (Raw)	Z (Fit)	M [68% Z(fit)]	Cohort distribution N	Wt(kg)[2/]	Biomass[3/]
0	1.23	1.23	1.23	1,000	-	
1	0.25	0.25	0.25	292	.062	16.01
2	0.25	0.25	0.25	227	.096	19.28
3	0.25	0.25	0.25	177	.129	20.20
4	0.25	0.22	0.15	138	.162	20.76
5	0.01	0.27	0.18	119	.196	21.34
6	0.31	0.34	0.23	99	.229	20.25
7	0.44	0.42	0.29	79	.263	18.04
8	0.48	0.53	0.36	59	.296	14.67
9	0.47	0.67	0.45	41	.330	10.90
10	1.03	0.84	0.57	26	.363	7.19
11	1.20	1.04	.71	15	.396	4.25
12	3.35	1.31	.89	7	.430	2.00

1/ Ages 0-3 assumed rates

2/ Weight at age from Alaska Department of Fish and Game test fishing samples

3/ $\text{Biomass} = \frac{No(1-e^{-m})}{M}$

Table 4.--Estimates of fishing mortality (F) of eastern Bering Sea Pacific herring by age group within year.

Age	1959	1960	1961	1962	1963	1964	1965	1966	1967
1	0.0000	0.0000	0.0001	0.0041	0.0000	0.0000	0.0000	0.0000	0.0008
2	0.0011	0.0004	0.0005	0.0362	0.0018	0.0000	0.0031	0.0000	0.0000
3	0.0147	0.0027	0.0027	0.0309	0.0262	0.0044	0.0026	0.0009	0.0079
4	0.0026	0.0190	0.0132	0.0107	0.0260	0.0089	0.0142	0.0042	0.0068
5	0.0265	0.0123	0.0305	0.0243	0.0085	0.0085	0.0144	0.0083	0.0188
6	0.0609	0.0428	0.0619	0.0626	0.0302	0.0016	0.0118	0.0224	0.0246
7	0.0701	0.0335	0.0516	0.1119	0.0365	0.0105	0.0068	0.0089	0.0151
8	0.2344	0.0417	0.0735	0.0992	0.1339	0.0128	0.0069	0.0067	0.0280
9	0.3029	0.0389	0.1481	0.1280	0.0796	0.0299	0.0010	0.0078	0.0298
10	0.0000	0.0400	0.1300	0.1000	0.0800	0.0300	0.0020	0.0100	0.0300

Age	1968	1969	1970	1971	1972	1973	1974	1975	1976
1	0.0015	0.0000	0.0000	0.0000	0.0015	0.0008	0.0029	0.0031	0.0030
2	0.0519	0.1186	0.0040	0.0480	0.0180	0.1973	0.0762	0.0083	0.0614
3	0.2277	0.2482	0.2225	0.0883	0.4306	0.1982	0.1855	0.0770	0.0706
4	0.3587	0.1503	0.8052	0.3080	0.6255	0.2899	0.1797	0.0368	0.4150
5	0.1853	0.1853	0.4081	0.7381	0.4499	0.1670	0.3555	0.0693	0.0097
6	0.3208	0.3295	0.5099	1.5340	0.1062	0.2422	0.4639	0.6062	0.0032
7	0.2473	0.5166	0.4653	1.7339	0.0000	0.0798	0.2471	0.5657	0.0319
8	0.2209	0.5747	0.4453	2.6796	0.1552	0.0486	0.3905	0.2061	0.0688
9	0.2977	0.4154	0.6879	2.6125	0.1550	0.0000	0.3900	0.0333	0.0768
10	0.3000	0.5000	0.7000	2.6000	0.1550	0.0000	0.3900	0.0000	0.0700

Age	1977	1978	1979	1980	1981
1	0.0000	0.0000	0.0000	0.0000	0.0000
2	0.0023	0.0000	0.0000	0.0000	0.0000
3	0.0710	0.1742	0.2449	0.0016	0.0160
4	0.0236	0.1483	0.4232	0.1142	0.1225
5	0.2243	0.0863	0.1087	0.1738	0.3882
6	0.0147	0.0747	0.0720	0.2285	0.2251
7	0.0142	0.0444	0.0955	0.2364	0.0948
8	0.1541	0.0275	0.0282	0.2049	0.0580
9	0.1500	0.0270	0.0280	0.2000	0.1300
10	0.1500	0.0000	0.0000	0.0000	0.0000

Table 5.--Age specific maturity for ages 1-12 for eastern Bering Sea Pacific herring [Naumenko (1979)].

Year	Age group 1	2	3	4	5	6	7	8	9	10	11	12
1959	0.000	0.029	0.338	0.856	0.965	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1960	0.000	0.029	0.338	0.701	0.965	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1961	0.000	0.029	0.338	0.701	0.897	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1962	0.000	0.000	0.326	0.874	0.990	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1963	0.000	0.050	0.189	0.451	0.750	0.985	1.000	1.000	1.000	1.000	1.000	1.000
1964	0.000	0.038	0.500	0.777	0.950	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1965	0.000	0.027	0.338	0.745	0.916	0.996	1.000	1.000	1.000	1.000	1.000	1.000
1966	0.000	0.025	0.338	0.789	0.935	0.997	1.000	1.000	1.000	1.000	1.000	1.000
1967	0.000	0.023	0.339	0.833	0.954	0.998	1.000	1.000	1.000	1.000	1.000	1.000
1968	0.000	0.021	0.339	0.877	0.973	0.999	1.000	1.000	1.000	1.000	1.000	1.000
1969	0.000	0.020	0.460	0.930	0.980	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1970	0.000	0.038	0.390	0.920	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1971	0.000	0.055	0.170	0.920	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1972	0.000	0.073	0.030	0.950	0.986	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1973	0.000	0.090	0.250	0.780	0.960	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1974	0.000	0.108	0.690	0.970	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1975	0.000	0.180	0.660	0.940	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1976	0.000	0.060	0.740	0.920	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1977	0.000	0.085	0.653	0.910	0.989	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1978	0.000	0.037	0.495	0.815	0.943	1.000	1.000	1.000	1.000	1.000	1.000	1.000
1979[1/]	0.000	0.059	0.427	0.856	0.965	0.999	1.000	1.000	1.000	1.000	1.000	1.000
1980	0.000	0.059	0.427	0.856	0.965	0.999	1.000	1.000	1.000	1.000	1.000	1.000
1981	0.000	0.059	0.427	0.856	0.965	0.999	1.000	1.000	1.000	1.000	1.000	1.000

1/ Pates for 1979-81 are assumed rates which are the 1959-78 average rates.

RESULTS AND DISCUSSION

The results show a decreasing trend in abundance to a low in 1973 and then an increasing to stable trend through 1981 (Tables 6 and 7). Estimates of total biomass ranged from a high of 1.73 million t to a low of 153 thousand t. Estimates of spawning biomass ranged from 80 thousand t to 1.45 million t.

The results confirm that herring abundance was much greater in the late 1960's than in the late 1970's and that a rapid decline occurred in the early 1970's, apparently due to overfishing, a series of weak year-classes (1968-71), and the demise of the very strong 1957 and strong 1956 and 1958 year-classes.

Examination of abundance at age in recent years indicates the fishery has been supported by the 1972-74 year-classes. It appears that the 1975 year-class was extremely weak, and the 1976 only slightly better, while the 1977 year-class appears to be of the same order of magnitude as those in 1972-75. Abundance of the 1978 year-class appears to be weak based on 1981 catches of age 3 fish and the assumption that 43% of the year-class recruited to the spawning population. Adjusting the 1981 observed frequency of age 3 herring in ADFG test net samples by the lowest observed maturation at age 3 (3% in 1972, Table 5) results in an estimate of abundance about equal to the 1977 year-class which means that the 1978 year-class could be significant in coming years. However, length-frequency data collected by U.S. observers indicated an increase in the mean length of herring in the second half of 1981 which supports the possibility of reduced age 3 abundance (Table 8).

The abundance estimates resulting from this analysis should not be considered to be absolute because of the uncertainty of natural mortality rates. The natural mortality rates utilized are very low with respect to rates recorded in southeastern Alaska (Skud 1963) and British Columbia (Tester 1955). The use of lower than actual natural mortality rates in cohort analysis produces low

Table 6.--Estimated numbers (billions), by age group, for Pacific herring in the eastern Bering Sea, 1959-81.

Age	1959	1960	1961	1962	1963	1964	1965	1966	1967
1	4.139	1.183	0.966	0.570	2.453	0.573	0.319	0.285	0.440
2	8.264	3.223	0.922	0.752	0.442	1.911	0.447	0.248	0.222
3	1.842	6.429	2.509	0.717	0.565	0.343	1.488	0.347	0.193
4	0.348	1.413	4.993	1.949	0.542	0.428	0.266	1.156	0.270
5	0.243	0.299	1.194	4.241	1.659	0.454	0.365	0.226	0.991
6	0.136	0.198	0.247	0.967	3.457	1.374	0.376	0.301	0.187
7	0.052	0.102	0.150	0.184	0.722	2.665	1.090	0.295	0.234
8	0.037	0.037	0.074	0.107	0.123	0.521	1.973	0.810	0.219
9	0.004	0.021	0.024	0.048	0.068	0.075	0.359	1.367	0.561
10	0.000	0.002	0.013	0.013	0.027	0.040	0.047	0.228	0.865
Sum	15.065	12.906	11.091	9.548	10.057	8.385	6.730	5.264	4.182

Age	1968	1969	1970	1971	1972	1973	1974	1975	1976
1	1.753	0.313	0.266	0.288	0.147	0.688	0.862	1.219	0.053
2	0.342	1.363	0.244	0.207	0.224	0.114	0.535	0.669	0.946
3	0.173	0.253	0.943	0.189	0.154	0.172	0.073	0.386	0.517
4	0.149	0.107	0.154	0.588	0.135	0.078	0.110	0.047	0.278
5	0.231	0.090	0.079	0.059	0.372	0.062	0.050	0.079	0.039
6	0.812	0.160	0.062	0.044	0.024	0.198	0.044	0.029	0.061
7	0.145	0.468	0.091	0.030	0.008	0.017	0.123	0.022	0.013
8	0.172	0.085	0.209	0.043	0.004	0.006	0.012	0.072	0.009
9	0.149	0.096	0.033	0.093	0.002	0.002	0.004	0.006	0.041
10	0.348	0.070	0.041	0.011	0.004	0.000	0.001	0.000	0.003
Sum	4.273	3.006	2.122	1.552	1.073	1.336	1.814	2.529	1.962

Age	1977	1978	1979	1980	1981
1	0.136	0.871	0.059	0.000	0.000
2	0.041	0.106	0.679	0.046	0.000
3	0.693	0.032	0.082	0.528	0.036
4	0.375	0.503	0.021	0.050	0.411
5	0.158	0.315	0.373	0.012	0.039
6	0.032	0.106	0.242	0.280	0.008
7	0.049	0.025	0.078	0.179	0.177
8	0.009	0.036	0.018	0.053	0.106
9	0.006	0.006	0.024	0.012	0.030
10	0.024	0.000	0.000	0.000	0.000
Sum	1.524	2.000	1.576	1.160	0.806

Table 7.--Estimated biomass (1,000 t) of Pacific herring in the eastern Bering Sea by age group, total biomass, and spawning biomass, 1959-81.

Age	1959	1960	1961	1962	1963	1964	1965	1966	1967
					1,000 t				
1	257.	74.	60.	35.	152.	36.	20.	18.	27.
2	790.	308.	88.	72.	42.	183.	43.	24.	21.
3	238.	829.	324.	93.	73.	44.	192.	45.	25.
4	57.	230.	811.	316.	88.	70.	43.	188.	44.
5	48.	59.	234.	830.	325.	89.	72.	44.	194.
6	31.	45.	57.	222.	793.	315.	86.	69.	43.
7	14.	27.	39.	48.	190.	700.	286.	78.	61.
8	11.	11.	22.	32.	36.	154.	584.	240.	65.
9	1.	7.	8.	16.	22.	25.	118.	451.	185.
10	0.	1.	5.	5.	10.	14.	17.	83.	314.
Sum	1,446.	1,589.	1,647.	1,669.	1,731.	1,630.	1,461.	1,238.	979.
Sp.B.	255.	597.	1,020.	1,451.	1,338.	1,376.	1,255.	1,125.	899.

Age	1968	1969	1970	1971	1972	1973	1974	1975	1976
1	109.	19.	16.	18.	9.	43.	54.	76.	3.
2	33.	130.	23.	20.	21.	11.	51.	64.	90.
3	22.	33.	122.	24.	20.	22.	9.	50.	67.
4	24.	17.	25.	95.	22.	13.	18.	8.	45.
5	45.	18.	16.	12.	73.	12.	10.	15.	8.
6	186.	37.	14.	10.	5.	45.	10.	7.	14.
7	38.	123.	24.	8.	2.	4.	32.	6.	3.
8	51.	25.	62.	13.	1.	2.	3.	21.	3.
9	49.	32.	11.	31.	1.	1.	1.	2.	14.
10	126.	26.	15.	4.	2.	0.	1.	0.	1.
Sum	684.	459.	328.	234.	156.	153.	189.	248.	248.
Sp.B.	524.	293.	213.	170.	106.	80.	87.	103.	139.

Age	1977	1978	1979	1980	1981
1	8.	54.	4.	0.	0.
2	4.	10.	65.	4.	0.
3	89.	4.	11.	68.	5.
4	61.	82.	3.	8.	67.
5	31.	62.	73.	2.	8.
6	7.	24.	55.	64.	2.
7	13.	7.	20.	47.	46.
8	3.	11.	5.	16.	31.
9	2.	2.	8.	4.	10.
10	9.	0.	0.	0.	0.
Sum	227.	255.	245.	214.	168.
Sp.B.	179.	171.	171.	169.	156.

Sp.B. = Spawning biomass.

Table 8.--Trend of Pacific herring mean fork length and modal length in the foreign trawl fishery in the eastern Bering Sea, 1976-77 to 1981.

Year	Mean fork length	Mode	Number of fish
1976-77	23.42	24	1,981
1977-78	24.31	24	7,981
1978-79	25.71	26	3,175
1979-80	25.81	25	4,874
1980-81	25.90	26	4,564
1981-	27.12	27	1,867

estimates of abundance; therefore, the results presented should be considered minimum estimates of abundance, since it is likely that natural mortality rates are somewhat higher. The fit of estimated numbers-at-age from cohort analysis to 1979-80 maturity adjusted ADFG test fishing samples was good (Table 9). The number of fish at age computed by the cohort analysis is more dependent on M than the terminal F values in these years, therefore, differences between calculated and observed values would be due to errors in natural mortality estimates. The only severe discrepancies were for the 1976 year-class at ages 3 and 4 which appears to be due to underestimation of the rate of maturation. The observed and calculated frequency of age 6 in 1979 also differed, but the reason is unclear. These comparisons indicate that natural mortality rates for fully recruited fish are near those used in the analysis.

Table 9.--Comparison of cohort analysis estimated number of Pacific herring by age in percentage to test fishing samples collected on the spawning grounds.

Age	1979		1980		1981	
	Observed 1/	Calculated	Observed	Calculated	Observed	Calculated
2	36.0	44.8	--	--	--	--
3	22.0	5.4	46.6	47.4	4.5	4.6
4	3.0	1.4	10.3	4.5	51.0	51.2
5	24.6	24.6	1.4	1.1	4.8	4.8
6	6.4	16.0	21.5	25.1	1.0	1.0
7	6.9	5.1	13.7	16.1	21.9	21.8
8	.2	1.2	5.7	4.8	13.1	13.1
9	1.0	1.6	.9	1.1	3.7	3.7

l/ Number at age from each fishing district was weighted by district proportion of total sample size and summed over all areas. Total number of age 2 were divided by 0.06 (average proportion mature at age 2), age 3 by 0.43, age 4 by 0.86, and age 5 by 0.97. Percentages were computed from this adjusted distribution.

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