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Average Density Index for Walleye Pollock, *Theragra chalcogramma*, in the Bering Sea

Loh-Lee Low and Ikuo Ikeda

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U.S. DEPARTMENT OF COMMERCE
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Terry L. Leitzell, Assistant Administrator for Fisheries

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Average Density Index for Walleye Pollock, *Theragra chalcogramma,* in the Bering Sea

LOH-LEE LOW[1] and IKUO IKEDA[2]

ABSTRACT

The data base and an average density index (ADI) procedure for assessing walleye pollock, *Theragra chalcogramma,* abundance in the eastern Bering Sea were evaluated. The data base consisted of daily catch-effort records of individual fishing vessels in the Japanese groundfish fishery from 1964 to 1976. Variances about the annual mean catch, effort, and catch per unit effort (CPUE) data were low. Coefficient of variation of annual CPUE data was in the 1-2% range for the data base after 1969 but higher in earlier years when the number of fishing records was lower. An ADI procedure is described which takes into consideration different types of vessels used in the fishery, species mix in the catch, distribution of pollock, and fishing pattern of the fleet. Data from five vessel class-gear types that fished mainly for pollock were selected to compute ADIs in four area-time cells. An overall ADI within these cells was determined, summarizing the results by vessel class-gear types and area-time cells. From 1964 to the early 1970s, overall ADI and CPUE trends increased as a result of increased pollock abundance and fishing power of vessels. For 2-3 years during the early 1970s, abundances of pollock were at peak levels. Beginning in 1972, abundance declined but stabilized during 1975-78 at an intermediate level when 1.1 million metric tons of walleye pollock were harvested annually.

INTRODUCTION

Catch-effort data from commercial fisheries can be very useful for monitoring abundance of fish stocks. The concept for its use is simple: if conditions of fishing and vulnerability of the stock to fishing remain fairly constant, the amount of catch for a standard unit of fishing effort, catch per unit effort (CPUE), should reflect abundance of the stock under exploitation (FAO 1976). However, conditions of the fishery and dynamics of the stock (and therefore its vulnerability to fishing) frequently change, complicating the use of CPUE. These changes and the quality of data are variables that may invalidate the use of CPUE for measuring stock abundance. It is, therefore, of great importance to collect and analyze catch-effort data carefully so that these and other factors do not bias indices of abundance.

In the eastern Bering Sea, catch-effort data from the Japanese trawl fishery have been the most consistent and important source of information for assessing walleye pollock, *Theragra chalcogramma,* abundance. Since 1964, these data have been collected in a detailed and systematic manner. From this data base, CPUE computations to assess abundance of the pollock resource have been made over several years and results reported in documents submitted to the International North Pacific Fisheries Commission (INPFC).

At the 1974 annual meeting of the INPFC, Japanese scientists presented an extension of the CPUE index used by U.S. scientists as a measure of pollock abundance termed an average density index (ADI). This ADI procedure involved some selection of pair trawl catch-effort data from the data base for its computations. Because the Japanese trawl fishery used various vessel-gear combinations and took a variety of species, there was some difficulty in data selection for deriving unbiased measures of pollock abundance. In addition, there was a need to evaluate whether the fundamental data is representative of all data collected since not all daily catch-effort records were incorporated into the data base used to derive ADI values. To resolve these questions, the Committee on Biology and Research of INPFC established a working group to evaluate the data and the ADI procedure for assessing pollock abundance. This paper reports on results of the working group's study on the bias and variability of catch-effort data and the standardization of ADIs as a measure of pollock abundance.

THE WALLEYE POLLOCK FISHERY

Walleye pollock is of the family Gadidae and is distributed throughout the North Pacific. Its life span is about 15 yr, but 2-6 yr olds are the major ages exploited by the fishery. This age range corresponds to fish weighing 91 g (24 cm fork length) and 817 g (49 cm fork length). Pollock is by far the most abundant demersal fish in the eastern Bering Sea (Pereyra et al. 1976)[3] and has been

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[3]Pereyra, W. T., J. E. Reeves, and R. G. Bakkala. 1976. Demersal fish and shellfish resources of the eastern Bering Sea in the baseline year 1975. Processed Rep., 619 p. Northwest and Alaska Fish. Cent., Natl. Mar. Fish. Serv., NOAA, 2725 Montlake Boulevard E., Seattle, WA 98112.

the major target species of foreign trawl fisheries there. It supports the largest single species fishery in the North Pacific.

The modern history of groundfish exploitation in the Bering Sea began in 1954, but the fishery for pollock did not begin in earnest until the early 1960s. At that time yellowfin sole, *Limanda aspera*, declined substantially in abundance (Forrester et al. 1978) and in 1964 mechanized techniques for processing pollock into surimi (a minced fish product) were successfully implemented on Japanese motherships and large factory stern trawlers (Bakkala et al. In press). As a result pollock catches increased more than tenfold between 1964 and 1972 (from 175,000 t to nearly 1.9 million t, Table 1). Catches declined steadily thereafter to <1 million t in 1977-78 due to declining stock abundance and fishery restrictions on the catch. This trend in stock abundance was generally monitored by CPUE data from the fishery, but the ADI procedure appeared to be a good measure of abundance as well. They both depended on data compiled from the Japanese trawl fisheries in the Bering Sea.

Table 1.—Annual catch of walleye pollock, in thousand metric tons, in the eastern Bering Sea, 1964-78.

Year[1]	Japan	USSR[2]	Republic of Korea	Taiwan	Total
1964	175	—	0	0	175
1965	231	—	0	0	231
1966	262	—	0	0	262
1967	550	—	0	0	550
1968	701	—	1	0	702
1969	830	27	5	0	862
1970	1,231	20	5	0	1,256
1971	1,514	220	10	0	1,744
1972	1,651	214	9	0	1,874
1973	1,476	280	3	0	1,759
1974	1,253	310	26	0	1,589
1975	1,137	217	3	0	1,357
1976	913	179	85	0	1,177
1977	869	63	45	1	978
1978	821	93	62	3	979

[1]Data for 1964-76 were reported by respective nations to the U.S. National Marine Fisheries Service.

Data for 1977-78 were estimated by the U.S. National Marine Fisheries Service.

[2]Union of Soviet Socialist Republics.

DATA BASE

Major nations participating in the pollock fishery are Japan, Union of Soviet Socialist Republics, Republic of Korea, and Taiwan (Table 1). Japan has accounted for more than 85% of walleye pollock catches (Forrester et al. 1978) and since 1964 has collected more detailed and complete catch-effort records on her fisheries than any other nation. It is this data base of catch-effort records where we place great reliance for monitoring stock abundance. The fundamental data collected were daily catch-effort statistics by species or groups, within statistical blocks (1° longitude by ½° latitude, Fig. 1), and by individual fishing vessels and gear type. Vessels were further classified according to 10 tonnage classes from 1 to 4,500 gross registered tons (GRT). Major gear types were pair trawls, Danish seines, side trawls, longlines, gill nets, and stern trawls.

For 1964-72, many daily catch-effort records for individual vessels were not incorporated by the Fisheries Agency of Japan into the data file for economic reasons. Rather, every third record of such records was selected for key-punching. These subsampled records were then extrapolated to represent the total fishery. Since 1973 all catch-effort records have been included in the data base. The total data base is maintained by the Fisheries Agency of Japan. Monthly summaries of the catch-effort information by statistical blocks by fishing gear type and vessel size class were subsequently made available to the United States and Canada as member nations in INPFC.

AVERAGE DENSITY INDEX

The ADI equation presented at the 1974 INPFC meeting by Japanese scientists[4] was as follows:

$$\text{ADI} = (\Sigma(A_i \times \emptyset_i))/(\Sigma A_i)$$

where i = a statistical block number,
A = area (km²) of each statistical block,
$\emptyset$ = catch per unit effort in metric tons per hour trawled within each statistical block.

The application of this procedure for walleye pollock involved some selection of catch-effort data from pair trawlers which they determined to be the most consistent gear type directed to pollock fishing activities in each statistical block. Statistical blocks used in the calculations were those where the daily pollock catch was greater than that of any other species. From these selected "pollock-majority" catch-effort data an ADI was computed for an area made up of several statistical blocks.

TOPICS OF ANALYSIS

Objectives of our study were to evaluate the data base and procedures used for calculating ADIs for pollock. Specifically, we chose four topics to:

1) determine if bias towards high or low catches was introduced in the data base by subsampling of daily data records during 1964-72;
2) conduct variability studies in pair trawl data used for ADI and CPUE computations;
3) compare pollock ADIs calculated from all-data and pollock-majority-data; and
4) identify area-time cells for more accurate assessment of pollock abundance.

[4]Fishery Agency of Japan. 1974. Pollock stocks in the eastern Bering Sea. Unpubl. manuscr., 38 p. Far Seas Fish. Res. Lab., 1000 Orido, Shimizu 424, Japan.

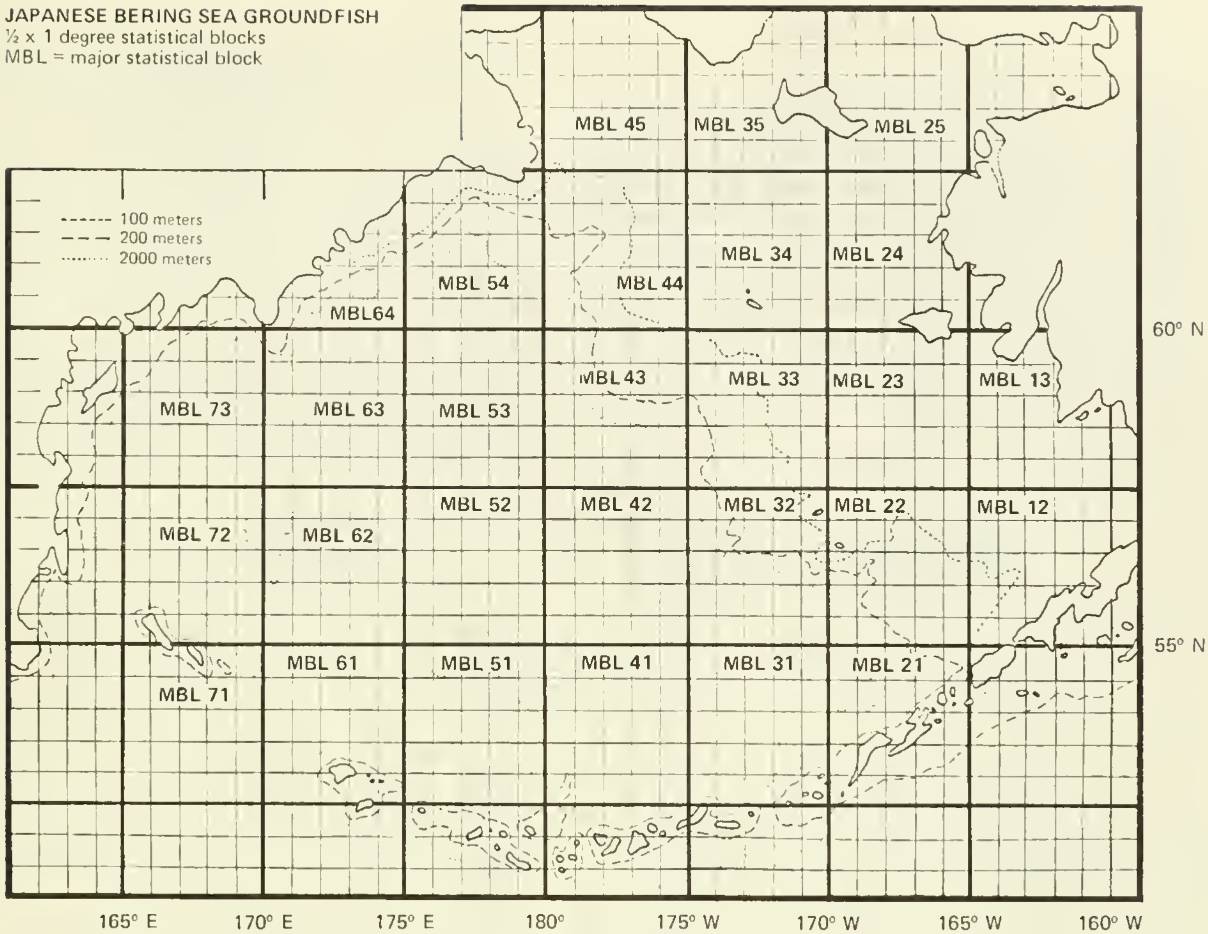

Figure 1.—Map of the Bering Sea showing statistical grids used in the Japanese groundfish data base.

EXAMINATION FOR BIAS IN THE 1964-72 DATA BASE

Since the data base for 1964-72 included only a third of the daily catch-effort records, we wanted to determine whether the partial data base is biased towards high or low catch levels by the subsampling procedures used. It was necessary to examine this question indirectly by using the complete 1973-76 data base because the missing records in the earlier 1964-72 data could not be easily restored. First we subsampled the 1973-76 data on pair trawlers in the same manner in which the 1964-72 data was created so as to create an equivalent file of one-third the daily fishing records. Pair trawl data were used because we determined that the vessels consistently accounted for the largest proportion (38%) of the walleye pollock caught, and should be most representative of pollock fishing activities (Table 2). As a result of this subsampling, two data files were created: a one-third pair trawl file and an all pair trawl file.

We compared these two files by testing if their monthly mean catch and effort data were statistically the same. This was achieved by *t*-tests of two means when their variances were unknown (Snedecor and Cochran 1967). The tests showed that the null hypothesis (that mean catch and effort of both data files were the same) was not rejected at the 5% level in all cases. Based on these tests, we concluded that subsampling of the 1964-72 data base probably resulted in a random sample of the population and was not biased towards high nor low catches.

Table 2.—Percentage of walleye pollock catches relative to total catches accounted for by major Japanese vessel-gear categories in the eastern Bering Sea, 1973-76.

	1973	1974	1975	1976
Type 1—Pair trawlers, 120-219 GRT	35	37	35	36
Type 2—All pair trawlers	39	37	38	37
Type 3—Stern trawlers, <300 GRT	4	5	7	6
Type 4—Factory trawlers, 1,500-3,500 GRT	9	10	10	9
Type 5—Factory trawlers, >3,500 GRT	28	26	27	28

[1]GRT = gross registered tons.
Source: Fishery Agency of Japan.

VARIABILITY STUDIES ON PAIR TRAWL DATA

Because the data records of Japanese groundfish catch-effort statistics that were available through INPFC were summaries of many daily trawls, variances about these statistics cannot be estimated. Therefore, we estimated variances of the fundamental daily catch, effort, and CPUE data for statistical interpretation of CPUE values. We selected the 120-219 GRT class of pair trawlers attached to the Japanese surimi mothership fishery for the analysis because these trawlers were probably the most representative vessels used in the fishery for monitoring pollock CPUE trends (Table 2).

The analysis by monthly and annual periods shows that standard deviations of mean catch, effort, and CPUE values decreased substantially after 1973 when the number of daily catch-effort records (sample size) were increased from earlier years (Table 3). Variances about the monthly and annual CPUE values calculated from daily catch-effort records were small after 1965. Coefficient of variation (CV) for the 1964 and 1965 data was 19% and 9%, when the sample sizes were small (Table 4). When the sample size approached 300 (1966-69), CV generally was below 4%. As the sample size increased and approached 5,000 (1970-76) the CV decreased to the 1-2% range.

A comparison of annual mean CPUEs at the 95% confidence level shows that pollock CPUE increased significantly each year from 1963 to 1969, followed by a significant decrease from 1969 to 1971 (Table 4). Another

Table 3.—Statistics on variability studies on catch-effort data for pair trawlers of the 120-219 gross registered ton class in the Japanese surimi (a minced fish product) mothership fishery in the eastern Bering Sea, 1964-76.

Year	Month	Sample size[1]	Mean catch[2]	Standard deviation	Mean effort[3]	Standard deviation	Mean catch per effort[4]	Standard deviation
1964	5	7	240	51	38.7	2.0	6.32	1.41
	6	6	195	31	45.8	6.4	4.20	.45
	7	6	475	118	33.3	2.0	13.79	2.67
	8	4	82	64	35.5	9.0	4.13	3.20
	9	7	0	0	29.1	2.5	.00	.00
Annual		30	201	40	36.4	2.0	5.62	1.11
1965	5	14	195	24	14.9	1.8	14.05	1.90
	6	6	156	32	16.7	1.1	9.76	2.19
	7	6	265	19	20.0	1.3	13.47	1.20
	8	10	284	15	20.2	.6	14.22	.88
	9	12	40	6	14.4	.8	2.78	.32
Annual		48	178	16	16.7	.7	10.66	.94
1966	5	20	198	11	23.4	.4	8.59	.57
	6	16	183	17	23.6	.4	7.86	.83
	7	20	168	13	24.0	.0	7.02	.54
	8	20	153	17	23.1	.6	7.04	.96
	9	16	84	12	22.9	1.8	3.74	.50
Annual		92	159	7	23.4	.4	6.94	.35
1967	3	30	319	30	41.8	1.6	7.77	.70
	4	30	540	42	24.9	1.6	23.66	2.22
	5	46	340	30	43.9	2.4	7.87	.49
	6	50	347	32	43.9	2.6	7.66	.57
	7	55	583	47	48.3	3.0	11.96	.50
	8	50	674	57	44.1	2.9	14.35	.49
	9	44	475	52	37.1	2.9	12.76	.92
Annual		305	477	18	41.7	1.1	11.88	.41
1968	3	36	831	56	30.5	1.7	30.90	2.83
	4	50	644	41	34.5	1.3	20.47	1.75
	5	78	692	36	35.9	1.6	20.08	.94
	6	80	743	48	40.0	1.8	19.74	1.29
	7	82	705	38	28.2	1.3	26.90	1.49
	8	83	798	47	34.8	1.7	23.71	1.14
	9	74	683	40	32.7	1.6	21.82	1.14
	10	15	649	103	35.7	4.0	18.91	2.22
Annual		498	723	17	34.1	.6	22.80	.53
1969	3	39	947	67	13.8	.9	80.89	7.55
	4	55	807	57	26.7	1.7	37.74	3.37
	5	75	594	41	38.2	2.1	18.85	1.65
	6	79	565	53	47.2	1.7	11.41	.91
	7	88	848	50	45.3	1.9	18.64	.86
	8	78	976	60	26.0	1.6	41.33	2.25
	9	61	980	67	31.7	2.1	33.45	1.66
Annual		475	802	22	34.8	.8	30.42	1.24

Table 3.—*Continued.*

Year	Month	Sample size[1]	Mean catch[2]	Standard deviation	Mean effort[3]	Standard deviation	Mean catch per effort[4]	Standard deviation
1970	3	68	1,335	79	25.7	1.4	64.23	5.36
	4	110	841	51	37.8	1.9	24.73	1.40
	5	160	537	34	42.2	1.5	13.74	.83
	6	202	851	35	44.3	1.5	20.26	.63
	7	205	1,070	41	37.2	1.5	32.52	.97
	8	199	909	41	42.3	1.4	22.74	.77
	9	181	898	41	38.0	1.3	23.99	.71
	10	24	257	32	23.6	.8	10.89	1.26
Annual		1,149	879	17	39.3	.6	25.39	.56
1971	3	113	1,121	56	29.1	1.3	43.46	2.43
	4	157	1,375	53	38.0	1.3	45.20	2.84
	5	249	782	29	46.5	1.2	21.07	1.21
	6	252	763	24	55.5	1.1	14.39	.52
	7	271	1,005	33	54.7	1.1	19.54	.73
	8	263	1,260	30	54.2	1.2	24.59	.60
	9	219	1,104	32	49.6	1.3	23.30	.57
	10	18	531	60	23.3	1.8	23.63	2.41
Annual		1,542	1,028	14	48.8	.5	24.75	.50
1972	3	125	1,442	68	25.5	1.0	61.13	2.87
	4	169	1,480	56	26.9	1.0	67.20	3.14
	5	329	713	25	46.3	1.0	16.29	.56
	6	329	725	27	45.8	1.1	16.87	.64
	7	342	1,241	33	45.2	1.1	30.26	.95
	8	321	1,331	42	43.0	1.1	34.26	1.06
	9	262	1,020	37	39.6	1.2	26.75	.64
Annual		1,877	1,078	16	41.4	.5	31.04	.59
1973	3	417	973	26	39.3	.5	26.13	.74
	4	555	985	20	51.9	.4	19.51	.42
	5	712	617	15	55.4	.7	11.60	.36
	6	920	729	20	51.7	.7	14.00	.34
	7	981	1,259	20	47.6	.6	28.35	.38
	8	964	1,088	16	44.7	.6	27.65	.44
	9	804	1,036	18	43.2	.8	28.00	.49
Annual		5,353	968	8	48.0	.3	22.39	.19
1974	4	590	1,013	19	38.6	.5	27.89	.60
	5	772	608	10	48.5	.5	12.99	.20
	6	1,046	727	10	45.8	.5	17.28	.31
	7	1,083	840	12	48.9	.6	18.85	.27
	8	1,068	853	12	50.7	.7	18.32	.22
	9	981	983	16	44.8	.7	24.55	.38
	10	20	655	36	43.4	1.7	15.76	1.27
Annual		5,560	832	6	46.8	.3	19.59	.14
1975	3	3	763	281	29.7	2.9	26.30	9.14
	4	391	634	15	43.8	.6	14.86	.34
	5	790	525	9	45.0	.5	11.78	.18
	6	1,019	614	8	45.9	.5	14.02	.17
	7	1,048	772	10	50.7	.6	16.88	.26
	8	1,034	798	9	45.1	.6	20.64	.41
	9	875	767	15	41.7	.5	18.24	.30
	10	150	615	17	43.5	.9	14.83	.48
Annual		5,310	695	4	45.6	.2	16.33	.12
1976	4	267	486	14	47.7	.5	10.74	.36
	5	737	446	8	54.7	.4	8.37	.16
	6	840	678	7	53.3	.5	13.94	.22
	7	867	864	8	49.0	.5	19.14	.26
	8	824	947	10	43.8	.5	24.54	.46
	9	743	756	9	37.5	.5	22.38	.36
	10	545	772	11	42.6	.5	19.10	.32
Annual		4,823	734	4	47.2	.2	17.54	.15

[1]Sample size is number of daily catch-effort records.
[2]Catch in 0.1 metric tons.
[3]Effort in 10-min trawling.
[4]Catch per unit effort in metric tons per 100-min trawling.

Table 4.—Statistics on variability studies on mean annual catch per unit effort (CPUE) of walleye pollock by pair trawlers of the 120-219 gross registered tons class in the Japanese surimi (a minced fish product) mothership fishery in the eastern Bering Sea, 1964-76.

Year	Mean annual CPUE (t/h)	±95% confidence level	Coefficient of variation (%)	Sample size (no.)
1964	3.37	1.31	19	30
1965	6.40	1.11	9	48
1966	4.16	0.41	5	92
1967	7.13	0.48	3	305
1968	13.68	0.63	2	498
1969	18.25	1.46	4	475
1970	15.23	0.66	2	1,149
1971	14.85	0.59	2	1,542
1972	18.62	0.69	2	1,877
1973	13.43	0.22	1	5,353
1974	11.75	0.17	1	5,560
1975	9.80	0.14	1	5,310
1976	10.52	0.17	1	4,823

significant increase occurred from 1971 to 1972. Thereafter, CPUE declined significantly from 1972 to 1975.

COMPARISON OF ADIs FROM ALL-DATA VERSUS POLLOCK-MAJORITY-DATA

The manner in which data were selected for ADI computations by the Japanese scientists and for CPUE computations by the U.S. scientists was different. Japanese scientists used data from those trawls that presumably targeted on walleye pollock, which were determined as those in which the catch of pollock was greater than that of any other species (pollock-majority-data). U.S. scientists used data from all trawls because pollock was the target species almost all the time.

Either procedure can produce biased indices of abundance. Abundance may be overestimated by the exclusion of catch-effort data when the proportion of pollock in catches was low. On the other hand, it may be underestimated when data were included from trawls that were not fishing pollock.

In order to compare the two procedures, we calculated ADIs for 1973-76 using all-data and pollock-majority-data. These calculations were based on data summarized by major statistical blocks (MBLs, Fig. 1) and months (MBL-months) from five vessel class-gear categories known to fish mainly for pollock in the surimi fishery (Table 2). These vessel-gear types were:

Type 1—Pair trawlers, 120-219 GRT from the mothership fishery.
Type 2—All pair trawlers combined from the mothership fishery.
Type 3—Stern trawlers smaller than 300 GRT from the mothership fishery.
Type 4—Factory stern trawlers of the 1,500-3,500 GRT class.
Type 5—Factory stern trawlers larger than 3,500 GRT.

Our calculations showed that differences in ADIs by the two procedures were generally small when they occurred and that ADIs were higher for pollock-majority-data (Table 5). Comparison of monthly ADIs (Table 6) shows that: 1) in over 80% of the observed number of

Table 5.—Average density indices, in metric tons per hour trawled, for all-data versus walleye pollock-majority-data by vessel-gear categories in the eastern Bering Sea, 1973-76.

	Vessel-gear category[1]				
	Type 1	Type 2	Type 3	Type 4	Type 5
1973					
All-data	11.0	10.8	7.6	8.1	10.9
Pollock-majority-data	11.3	11.1	7.6	8.2	10.8
1974					
All-data	10.1	10.0	7.0	6.4	8.4
Pollock-majority-data	10.2	10.0	7.1	6.5	8.5
1975					
All-data	9.3	9.2	5.9	5.8	7.1
Pollock-majority-data	9.3	9.2	5.9	5.8	7.1
1976					
All-data	10.5	10.4	6.6	5.6	8.0
Pollock-majority-data	10.6	10.5	6.6	5.6	8.0

[1]Type 1—Surimi (a minced fish product) mothership, pair trawlers, 120-219 gross registered tons (GRT).
Type 2—Surimi mothership, all pair trawlers.
Type 3—Surimi mothership, stern trawlers, <300 GRT.
Type 4—Surimi factory stern trawlers, 1,500-3,500 GRT.
Type 5—Surimi factory stern trawlers, >3,500 GRT.

Table 6.—Number of major statistical block months in which average density indices computed from all-data versus walleye pollock-majority data in the eastern Bering Sea were the same, differed by 0.1, or differed by more than 0.1 metric ton per hour trawled.

Vessel class-gear type[1]	1973 differences				1974 differences				1975 differences				1976 differences			
	Total	None	0.1	>0.1	Total	None	0.1	>0.1	Total	None	0.1	>0.1	Total	None	0.1	>0.1
1	29	21	3	5	30	24	4	2	31	31	0	0	31	28	0	3
2	29	22	2	5	30	23	5	2	31	30	1	0	31	28	0	3
3	25	24	1	0	33	21	5	7	37	34	1	2	41	40	1	0
4	57	49	3	5	52	48	0	4	47	46	0	1	52	50	1	1
5	65	56	5	4	64	51	4	9	59	52	4	3	60	56	1	3

[1]Type 1—Surimi (a minced fish product) mothership, pair trawlers, 120-219 gross registered tons (GRT).
Type 2—Surimi mothership, all pair trawlers.
Type 3—Surimi mothership, stern trawlers, <300 GRT.
Type 4—Surimi factory stern trawlers, 1,500-3,500 GRT.
Type 5—Surimi factory stern trawlers, >3,500 GRT.

MBL-months, the two sets of ADIs were similar and 2) the frequency and magnitute of observed differences were fewer and lower in the most recent years. We found that differences occurred most frequently in the southeastern Bering Sea (MBLs 21 and 22) during March-June for pair trawlers and in the central and northern Bering Sea (MBLs 32, 33, 43, and 44) during December-March for factory trawlers.

These differences occurred in times and areas where species other than pollock were caught in large quantities. As the proportion of species other than pollock increased in the catch, differences became greater. The differences, however, were not significant although exclusion of data from poor pollock catches by one criterion resulted in ADIs that were on the high side and inclusion of all data by the other resulted in lower ADIs. Since we cannot distinguish which ADI was truly indicative of pollock abundance and not biased by changed in species composition, it was necessary to define index area-time cells which more accurately reflect trends in abundance.

INDEX AREA-TIME CELLS

Based on distributional pattern of pollock and its life history features (Pereyra et al. 1976 see footnote 3) we identified four area-time cells (Fig. 2) which consistently accounted for high proportions (75% or more) of pollock in the catch for ADI computations.

Area-time cell I — MBLs 21 and 22, March-May, which represents the main spawning area during the spawning period.

Area-time cell II — MBLs 21 and 22, July-September, which represents the main spawning area during a feeding period.

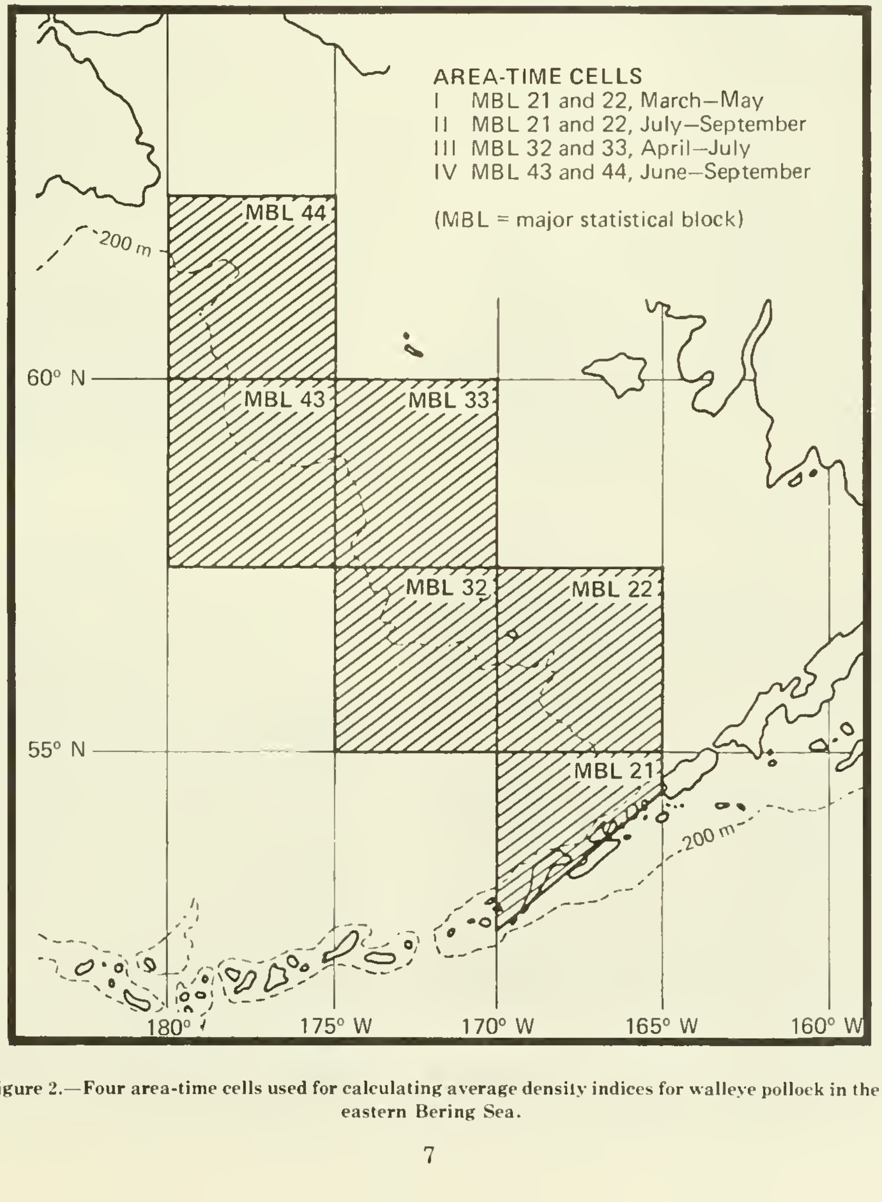

Figure 2.—Four area-time cells used for calculating average density indices for walleye pollock in the eastern Bering Sea.

Area-time cell III — MBLs 32 and 33, April-July, which represent the transitional area (between spawning and feeding grounds) during a transitional period (between spawning and feeding periods).

Area-time cell IV — MBLs 43 and 44, June-September, which represents the northern feeding area during a feeding period.

Each area-time cell was selected to delineate a unique phase of the distribution of the pollock population during the year. From catch distribution patterns, we also determined that these phases of distribution were usually repeated during the same area-time cell each year, thereby providing comparability of ADIs from year to year.

After the selection of these four area-time cells, ADIs were computed for all vessel-gear categories except Type 2, which was already considered in Type 1. The computations were made using all-data as opposed to pollock-majority-data within each cell because their results were not expected to be significantly different. The equation used to determine these ADIs was:

$$\mathrm{ADI}_{ag} = \left(\sum_{i=1}^{n_a} (A_{iag} \times \phi_{iag})\right) / \left(\sum_{i=1}^{n_a} A_{iag}\right)$$

where a = 1,2,3,4 index area-time cells
g = 1,2,3,4 vessel-gear types
i = 1,2, . . . n statistical block number
n_a = number of statistical blocks selected for computation in index area-time cell a
ϕ_{iag} = catch per unit effort (metric tons per hour trawled) by gear-vessel type g in statistical block i within index area-time cell a
A_{iag} = area (km^2) covered by vessel-gear type g which is made up of statistical blocks i within area-time cell a.

The results shown in Table 7 are ADIs calculated by the above equation from monthly data by vessel-gear type within each cell. A summarization of these monthly ADIs by cell and gear type is presented in Table 8. In this table, ADIs were weighted by the magnitude of catches and then expressed in percentages relative to 1976 pair trawl ADIs.

In the interpretation of ADI trends within area-time cells we also considered changes to the accustomed fishing pattern due to factors such as fishing regulations. Area-time cell I probably would not provide a good indicator of pollock abundance for 1973-76 because that cell was partially closed to trawling during some years (INPFC 1979). Time-area closures have not been a factor in the other three cells (II-IV) and fishing patterns did not change significantly during 1973-76. Thus, ADIs were better indicators of stock abundance in these latter three cells than in cell I.

The trend in ADIs shows that relative pollock abundance declined from 1973 or 1974 to 1976 in all cells (Table 9). Most of the decline occurred between 1973 and 1974, and from 1974 to 1976 relative abundance remained fairly stable.

TRENDS IN WALLEYE POLLOCK ABUNDANCE

Since we analyzed the 1964-76 data base at the working group meeting in 1977, we have updated the analyses on annual CPUE and ADI trends through 1978 as shown in Figure 3. They are trends of pair trawl data from the surimi mothership fishery. From 1964 to the early 1970s, there was a general increase in the CPUE and ADI trends which resulted from increased pollock abundance and fishing power of vessels. Catch composition and trends (Forrester et al. 1978) showed that pollock became increasingly abundant as the fishery progressed in the 1960s. At the same time, there must have been considerable learning experiences by fishermen which contributed to higher CPUEs as noted by Low (1974). Technological changes in the fishing fleet also took place, which no doubt increased the size and overall efficiency of fishing vessels. Effects of these physical changes on CPUE and ADI trends were probably held rather constant by selecting data from our five standard vessel class categories for computations. However, we cannot separate the effect of increased fishing power of vessels from the effect of increased pollock abundance in CPUE and ADI trends from 1964 to the early 1970s.

For 2-3 yr during the early 1970s, abundance of pollock appeared to be at peak levels. By this time most of the technological changes and human learning factors that contributed to increased fishing power have probably stablized. Beginning in 1972, both CPUE and ADI trends decreased but stabilized during 1975-78 at an intermediate level when 1.1 million t of pollock were harvested annually.

SUMMARY

The data base and an average density index (ADI) procedure for assessing abundance of walleye pollock in the eastern Bering Sea were evaluated. This data base was made up of daily catch-effort records of individual fishing vessels in the Japanese groundfish fishery. For the period 1964 through October 1972, the data base consisted of a third of the total daily catch-effort records. Thereafter, all daily records were included. Based on pair trawl data from the 120-219 gross registered ton class of vessels in the surimi mothership fishery, it was determined that one-third of the records provided a statistically representative sample of the entire data base. It was further determined that monthly summaries of daily catch-effort records that have been submitted by Japan to INPFC and used by U.S. scientists for assessing abundance of walleye pollock were not significantly different from daily records used by the Fisheries Agency of Japan in their assessments.

Table 7.—Comparison of average density indices, in metric tons per hour trawled, for walleye pollock in the eastern Bering Sea by area-time cells (see Figure 2 and text) and vessel-gear categories, 1973-76.

Area-time cells	Surimi mothership pair trawlers (120-219 GRT)[1]					Surimi mothership stern trawlers (300 GRT)					Surimi factory stern trawlers (1,500-3,500 GRT)					Surimi factory stern trawlers (>3,500 GRT)				
Cell I	Mar.	Apr.	May		Annual	Mar.	Apr.	May		Annual	Mar.	Apr.	May		Annual	Mar.	Apr.	May		Annual
1973	14.1	10.8	5.5		9.8	6.6	7.3	2.5		6.6	7.9	7.6	5.7		7.0	11.0	8.9	7.2		9.7
1974	—	12.9	7.2		9.9	9.1	10.0	—		9.7	5.5	6.7	6.1		6.4	7.6	6.1	4.7		6.2
1975	—	8.5	6.8		7.5	7.6	4.3	3.1		4.2	6.8	4.9	2.7		4.8	9.1	6.4	4.6		5.9
1976	—	6.4	3.3		4.5	—	4.5	2.7		3.4	5.3	3.4	3.3		3.9	6.5	5.9	3.9		5.2
Cell II	July	Aug.	Sept.		Annual	July	Aug.	Sept.		Annual	July	Aug.	Sept.		Annual	July	Aug.	Sept.		Annual
1973	—	—	—		—	—	—	—		—	—	—	—		—	43.1	—	—		43.1
1974	—	11.8	13.4		12.8	7.2	6.3	6.8		6.6	8.7	5.5	8.4		7.5	11.5	10.8	9.6		10.5
1975	9.8	9.6	12.8		10.9	9.3	5.8	8.8		7.8	7.7	6.6	8.7		7.6	9.0	8.9	12.8		10.1
1976	10.9	17.8	13.9		13.9	10.2	12.7	6.4		9.8	6.5	6.2	4.4		5.9	7.7	7.7	8.8		8.0
Cell III	Apr.	May	June	July	Annual	Apr.	May	June	July	Annual	Apr.	May	June	July	Annual	Apr.	May	June	July	Annual
1973	7.0	7.7	10.6	16.7	10.8	8.3	9.7	2.7	12.9	8.2	10.0	6.6	7.6	11.1	9.0	10.6	7.3	7.6	19.8	10.7
1974	7.3	7.4	8.2	10.9	8.8	7.8	5.4	6.7	7.3	6.9	6.8	6.5	5.2	7.8	6.6	7.2	4.1	5.5	10.6	7.3
1975	5.6	7.6	7.8	9.0	8.0	7.3	2.5	2.4	6.4	4.2	4.6	4.2	4.2	7.1	5.3	6.7	5.3	4.3	8.5	6.3
1976	5.7	5.6	8.4	10.7	8.6	4.9	3.9	7.2	6.4	5.8	4.7	3.3	3.5	6.8	4.8	5.0	4.7	7.5	7.0	6.2
Cell IV	June	July	Aug.	Sept.	Annual	June	July	Aug.	Sept.	Annual	June	July	Aug.	Sept.	Annual	June	July	Aug.	Sept.	Annual
1973	14.1	14.9	15.2	15.1	15.1	7.3	10.2	6.8	6.0	7.6	5.6	9.1	10.0	6.4	8.2	8.7	15.1	13.8	8.2	11.5
1974	9.9	8.6	9.2	11.9	10.0	5.8	6.2	—	-	6.0	3.5	3.9	5.0	—	4.0	5.0	4.5	9.6	13.1	7.7
1975	8.7	8.3	11.8	9.8	9.6	5.0	5.1	—	4.0	4.7	4.3	4.3	12.6	—	4.8	4.7	9.7	12.3	5.3	6.2
1976	6.2	8.7	13.3	11.6	10.9	5.1	4.1	3.7	5.7	4.5	7.5	9.0	5.8	15.6	10.0	7.3	6.8	—	8.9	8.2
Summary					Annual					Annual					Annual					Annual
1973					11.0					7.6					8.1					10.7
1974					10.1					7.0					6.4					8.4
1975					9.3					5.9					5.8					7.1
1976					10.5					6.6					5.6					8.0

[1] Surimi is a minced fish product; GRT is gross registered tons.

Table 8.—Annual average density indices (ADIs; in metric tons per hour trawled) and relative ADIs (as percentage of 1976 ADI) for walleye pollock in the eastern Bering Sea by area-time cells (see Figure 2 and text) and vessel-gear categories, 1973-76.

Area-time cell	Mothership pair trawlers (120-219 GRT)[1]			Mothership stern trawlers (<300 GRT)			Factory stern trawlers (1,500-3,500 GRT)			Factory stern trawlers (>3,500 GRT)			Gear summary	
	Catch (1,000 t)	ADI	Relative ADI	Catch (1,000 t)	ADI	Relative ADI	Catch (1,000 t)	ADI	Relative ADI	Catch (1,000 t)	ADI	Relative ADI	Relative ADI	Standard ADI[2]
Cell I														
1973	124	9.8	218	19	6.6	194	17	7.0	179	41	9.7	107	204	9.2
1974	88	9.9	220	5	9.7	285	4	6.4	164	21	6.2	119	202	9.1
1975	19	7.5	167	7	4.2	124	4	4.8	123	16	5.9	113	147	4.4
1976	23	4.5	100	6	3.4	100	6	3.9	100	27	5.2	100	100	4.5
Cell II														
1974	31	12.8	92	27	6.6	67	39	7.5	127	87	10.5	131	114	15.8
1975	78	10.9	78	39	7.8	80	33	7.6	129	73	10.1	126	102	14.2
1976	98	13.9	100	38	9.8	100	26	5.9	100	70	8.0	100	100	13.9
Cell III														
1973	112	10.8	124	14	8.2	141	0	9.0	180	36	10.7	173	140	12.0
1974	126	8.8	107	17	6.9	119	12	6.6	138	28	7.3	118	108	9.3
1975	152	8.0	93	9	4.2	72	14	5.3	110	38	6.3	102	95	8.2
1976	105	8.6	100	18	5.8	100	11	4.8	100	30	6.2	100	100	8.6
Cell IV														
1973	258	15.1	139	61	7.6	169	41	8.2	82	170	11.5	140	140	15.3
1974	181	10.0	92	10	6.0	133	8	4.0	40	36	7.7	94	92	10.0
1975	56	9.6	88	10	4.7	104	3	4.8	48	8	6.2	76	87	9.5
1976	69	10.9	100	4	4.5	100	1	10.0	100	8	8.2	100	100	10.9
Cell summary														
1973	517	11.0	105	120	7.6	115	122	8.1	145	420	10.7	134	121	12.7
1974	462	10.1	96	104	7.0	106	122	6.4	114	335	8.4	105	102	10.7
1975	369	9.3	89	105	5.9	89	112	5.8	104	277	7.1	89	91	9.6
1976	354	10.5	100	99	6.6	100	89	5.6	100	263	8.0	100	100	10.5

[1] GRT is gross registered tons.
[2] Standardized to mothership pair trawler ADI units.

Table 9— Overall average density indices (ADIs; as percent of 1976 metric tons per hour trawled) for walleye pollock in the eastern Bering Sea computed from ADIs in area-time cells which were weighted by catches, 1973-76.

Year	Feeding season, southern area (Area-time cell II)		Transitional season, transitional area (Area-time cell III)		Feeding season, northern area (Area-time cell IV)		Summary	
	Catch (1,000 t)	Relative ADI	Catch (1,000 t)	Relative ADI	Catch (1,000 t)	Relative ADI	Catch (1,000 t)	Relative ADI
1973	0	—	170	140	530	140	700	140
1974	184	114	183	108	235	92	602	104
1975	223	102	213	95	77	87	513	97
1976	232	100	164	100	82	100	478	100

Variances about the monthly and annual means of catch, effort, and catch per unit effort (CPUE) calculated from the daily records were small for most years. In 1964 and 1965 when the number of daily records was small, the coefficients of variation were 19% and 9%. As the annual sample size of daily records approached 300, coefficients of variation for CPUE generally declined to below 4%, which was about the level for the data from 1966 to 1969. As the fishery expanded after 1969 and the number of daily fishing records approached 5,000; coefficients of variation were reduced to between 1% and 2%.

Figure 3.—Trends in catch per unit effort (CPUE) and average density index (ADI) for walleye pollock in the eastern Bering Sea, 1964-78.

Catch-effort records of two types have been used for calculating ADIs: 1) records where walleye pollock were the most abundant species in the catch which have been defined as "pollock-majority-data" and 2) all-data records. Based on records from five vessels class-gear types, it was determined that ADIs resulting from the two procedures were statistically the same in 80% of the cases studied because of high proportion of pollock in catches. However, in certain area-time cells where other species formed a relatively high proportion of the catch, the two procedures resulted in lower ADIs. Therefore, use of data only from pollock-majority-data may cause abundance to be overestimated while use of all-data may cause it to be underestimated because some of the effort may have been directed to another species. Thus, ADIs calculated by either method may be biased towards the high or low side and may not be directly comparable from year to year.

In an attempt to reduce such bias in ADIs, four area-time cells were identified as potential index areas for abundance computations. Three of these four cells turned out to be good index areas for pollock. The ADI procedure used thus resulted in an extension to the original ADI procedure by Doi et al. (1972) to include: 1) selection of vessel-gear categories that were most representative of pollock fishing activities and 2) selection of area-time cells that provided good indexing areas.

Since then, the study has been updated to include data analyses from 1964 to 1978. Trends in CPUE and ADI show that from 1964 to the early 1970s, there was a general increase in the abundance of pollock. This trend was the result of increased pollock abundance and fishing power of vessels. However, we cannot determine the separate effect of these two factors. For 2-3 yr during the early 1970s, abundance of pollock appeared to be at peak levels. Beginning in 1972, both CPUE and ADI trends decreased but stabilized during 1975-78 at an intermediate level when 1.1 million t of walleye pollock were harvested annually.

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