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Derivation of Catch Per Unit Effort from Commercial Fishing Statistics for the Bering Sea 1964-73

by

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ABSTRACT

Japanese commercial catch-effort data are the most detailed and complete, in temporal and areal sequence, of all data sources for determining catch per unit effort (CPUE) indices of relative abundance of demersal fish stocks in the Bering Sea. To assess any stock, however, the data have to be screened and selected since the fishery is multi-species and multi-gear in nature. The most difficult problems are (1) analysis of fishing effort to determine the proper levels of fishing effort attributed to catch the stock and (2) subsequent adjustments to the selected effort values due to changes in their fishing power--mainly through advancing technology and learning processes. In this paper, the derivation of CPUE from four papers on walleye (Alaska) pollock, *Theragra chalcogramma*, the primary target species of the fishery, are used to illustrate procedures to describe trends in the fishery and the fish stocks. As the species diminish in overall importance from occasional target to incidental species, the problems associated with selecting proper levels of effort for that apecies becomes more difficult. Although the problems of CPUE analysis in the Bering Sea involving multiple species are very similar to those encountered elsewhere in the world, the solutions will depend on the species mix and the data base.

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INTRODUCTION

In a typical fishing operation, an input of fishing effort results in an output of catch. These two fundamental input-output quantities--catch and fishing effort--then provide the basic information used for assessing the fishery. In order to use the relation that catch per unit of fishing effort (CPUE) reflects the true abundance of stocks exploited, the effective amount of fishing effort has to be determined. Unfortunately, most of the problems associated with the use of fishing effort information, especially that of commercial fisheries as pointed out in ICES (1954) and Gulland (1956), are difficult to solve. The exploited fish stocks change intricately in space and time. Likewise, fishing effort directed to catch certain stocks also changes.

In the Bering Sea, commercial catch-effort information form the most complete set of data available for studying the demersal fishery. Although such fundamental input-output information may not be adequate to describe details of the fishery, it is still possible to describe trends in the fishery and fish stocks. The most difficult problems are in fishing effort analysis to determine the proper levels of fishing effort attributed to catch certain stocks. Such an analysis is complicated by the multi-species, multi-gear, and multi-national structure of the fishery.

Therefore the emphasis in this paper is on fishing effort analysis which will involve determination of fishing effort contributed towards catch of certain individual species and adjustments to catchability coefficients so that the proper levels of fishing effort may be determined. The resulting information on effort will then be used with catch information to evaluate the status of demersal fish stocks in the Bering Sea. The determination of catch per unit of effort (CPUE) index of relative stock abundance for the walleye (Alaska) pollock, *Theragra chalcogramma*, will be used primarily to illustrate analysis of CPUE for demersal stocks in the Bering Sea.

FISHING EFFORT ANALYSIS

SOURCE AND ADEQUACY OF DATA

Japan, through the International North Pacific Fisheries Commission (INPFC), provides most of the available statistics on more than 10 important species of demersal fish caught in the Bering Sea. Also available are limited commercial catch and effort statistics of non-INPFC member nations (Republic of Korea and the Soviet Union) participating in fisheries on a fairly wide scale.

However, of all the data sources, the commercial catch-effort data from Japan form the most complete source for fisheries analysis. Supplementary biological statistics such as age-length structure are also collected for important species in research cruises or by scientists aboard commercial fishing vessels by special agreement.

The major developments of demersal fisheries in the Bering Sea took place after World War II. Since 1954, Japan and later the Soviet Union (since 1958) mounted such intensive fisheries that by 1964, a number of stocks had already been over-harvested (Pruter, 1973). For example, the eastern Bering Sea yellowfin sole, Limanda aspera, catch has never recovered to the 1961 peak of 600 thousand metric tons (MT) (Fig. 1).

This period (1954-63) can be considered the first of two phases of the postwar fishery in which yellowfin sole was the principal species harvested. Unfortunately, systematic detailed statistics from the fisheries were not collected until late 1963 and by then much of the history on early exploitation of the resources were lost. As a result, the original stable conditions of some of the species (yellowfin sole; sablefish, Anoplopoma fimbria; and Pacific ocean perch, Sebastes alutus) cannot be traced because of inadequate data.

Since 1963, the total catch of demersal fish increased from a pre-1963 peak of about 600 MT to more than 1.9 million MT (Fig. 1) at the present. This period is the present phase when pollock is the principal species. It is also one when the status of some exploited stocks may be inferred from collected statistics.

The Japanese commercial fisheries data are detailed to catch-effort by year, month, gear type, degree longitude, half-degree latitude, species, and, since 1968, by vessel size category. Effort units are expressed, accordingly, to gear used.

To use the data base, one will have to assume that catch estimates are correct. This may not always be the case, especially when the amount of 'discards' at sea are not accounted for. The problem of discards at sea is probably less important after 1967 when most of the fish caught have been utilized.

EFFORT RELATED TO SPECIES

The fundamental use of catch-effort information is to compute CPUE indices of relative abundance for different species or stocks. Although there is inadequate information to delineate stock of the same species in the Bering Sea, there are indications (Moiseev et al., 1963-70; Low, 1974) that each species may be considered a stock for study.

Since there is a great diversity of species caught with each unit of fishing gear, the CPUE analysis may proceed according to a single species or a pooled species approach. In the single species approach, determination of fishing effort and hence CPUE of each demersal fish species is treated in turn as though each is a single species system. The important assumption is that there is no species interaction. However, this is not true when (1) competition for food and space and (2) predation are considered. There is little that can be done about including interaction terms because so little is known about demersal community interactions.

Alternatively, one may treat the species complex as a whole and determine empirically the relation between total effort and the combined catch of all species as though in a single-species situation (Gulland, 1972). The advantage of this pooled-species approach is that it is simple and will probably include some effects of species interactions.

Whichever approach is used, it is still necessary to separate recorded nominal fishing effort from the data base into (1) effort directed to catch a certain species or some pooled species (f_D) from (2) other effort that is not directed to catch species x (f_{ND}). Species-directed nominal fishing effort can then be used in the simple catch equation of $C = q\ f_D\ B$ where C is catch, q is the catchability coefficient of f_D, and B is the stock biomass.

From this basic catch equation and assuming that q is known or constant, inferences may then be made regarding the status of the exploited stock. However, q is changed by many factors and has to be taken into account when data of different areas or time periods are compared. This adjustment to q will be covered in the next section.

In the procedure of selecting f_D mentioned, the multi-species problem of removing several species simultaneously in a single fishing operation is not quite solved. Even if f_D is selected, it may be necessary to partition it into one part that is effective to harvest species x (f'_D) and another which does not (f''_D). Practically it is very difficult to partition effort, but an attempted procedure by Chang (1974) will be illustrated.

CATCHABILITY COEFFICIENT ADJUSTMENTS

Associated with each gear type, the catchability coefficient, defined as the ratio of fish caught to the stock for a given unit of fishing effort (Ricker, 1958), changes with time and place. It is a function of some important factors such as:

1. Random haul variations
2. Weather
3. Cyclical (seasonal or diel variations of fish distribution
4. Density of fish in fishing ground

5. Behavior of fish with respect to fishing gear
6. Skill of fishermen, especially of skippers to select good fishing grounds and fish schools
7. Distribution of fishing fleet in time with respect to that of fish
8. Power and size of fishing vessels
9. Type and size of fishing gear

Large random haul to haul variations will be reduced when thousands of separate fish operation data are combined. Variations due to weather will also be reduced when data are averaged over a period of time. Variations due to behavior of fish with respect to seasonal and diel movements are most likely to be reduced when data are compared for certain periods of the year in similar locations and, if necessary, for certain times of the day. Behavioral responses with respect to the fishing gear are usually difficult to account for. The responses are probably size dependent. Herding or avoidance effects could be affected by the density of the fish in the path of the fishing gear. As a first approximation, herding or avoidance factors may be assumed as one for trawl sweeps for most bottom species.

Variations due to the skill of fishermen to select good fishing grounds, detect fish schools and the skippers' ability to move the fishing vessels in a timely manner are very important in the fisheries. Since the vessels operate in fleets with good daily communications between vessels from the same company, it is assummed that information of more productive fishing grounds are circulated and the areas fished heavily. As fish detection and communications systems got better each year, q must also have increased with time. Also, the abilities of the fishermen must have improved. All these human factors are difficult to quantify but some form of a "learning curve" may be appropriate for adjusting q from year to year.

Much of the variations in q are the result of fishing gear and techniques which may be parameterized. Variations due to technological changes in fishing gear and vessels may be partially adjusted. Gulland (1956) calculated fishing powers of different gear-vessel types to adjust fishing effort to a standard. With the use of high speed computers, it is possible to adjust fishing effort according to fishing powers of individual vessel and gear throughout the vessel's fishing season. However, as in most commercial operations, catch-effort data associated with individual vessels are proprietary in nature and have been summarized so that the finest level of data identification is to gear-vessel size classification only.

Though it is not possible to account for all the major sources of variation in q, it is possible to reduce some of the variability if fishing effort information is grouped to representative or effective effort for a certain species by time period and area. Such selected fishing effort units may then be adjusted with fishing power increases due to such factors as technological changes. In addition to much technological change in the Bering Sea demersal fisheries, the experience and skill of fishermen were rapidly added, and these two factors--technology and learning--are of primary importance in q.

CATCH PER UNIT OF EFFORT

The concept of catch per unit of effort as a measure of relative stock abundance is well documented in such papers as Ricker (1958), Beverton and Holt (1957), and Gulland (1969). Some case studies of CPUE for some

demersal fish species, especially the target species of pollock, yellowfin sole, Pacific ocean perch, and sablefish are presented. A more useful result of the CPUE excercise is the use of catch and total standardized effort units in stock size, yield, and recruitment derivations. These follow-up exercises are quite standard in population dynamics and will not be included in this paper.

TARGET SPECIES

Pollock

Pollock make up about 85% of total demersal fish harvested and in certain areas and time, it is the target species of the Japanese mothership mince-meat ("surimi") fleet and the North Pacific trawl fleet. Associated with mothership fleets are catcher boats operating Danish seines and pair trawls for pollock in the continental shelf region. The side and stern trawlers seek pollock in the slope region. Therefore, by picking out data belonging to certain gear-vessel type in certain areas and time, the fishing effort exerted to catch pollock may be extracted from the summarized data base.

With the use of three-dimensional computer graphics for displaying pollock catch by area, time, and gear-vessel type (Fig. 2, Low 1974)[1/], time and areal data refinements may be quickly scanned. For example, it is possible to select pair trawl effort in the shelf region to compute indices of pollock abundance. The pair trawlers have contributed increasingly more to the pollock catch since 1964 (Table 1) as a result of increasing effort. Effort and hence catch by other gear types, such as Danish seiners and side trawlers, has decreased.

Pair trawl has also been selected as a possible representative gear type by Alton and Fredin[2/] and by Takahashi[3/] to determine relative pollock abundance because the effects of increasing fishing power due to horsepower changes of the vessels may be considered. This assumption that q is related to horsepower of the vessel is supported by Maeda (1972) who reported that catch by pair trawlers per hour trawling proportionately increases with brake horsepower.

Alton and Fredin[2/] summarized their analysis by five large areas (Fig. 3) designed for studies of Pacific halibut, Hippoglossus stenolepis, and over the period of a year. The annual effort data is then multiplied by the annual mean vessel horsepower. Catch per thousand pair trawl-horsepower hours are computed and the expected total fishing effort is computed by dividing total catch of pollock by all nations with catch per unit of pair trawl-horsepower effort.

Takahashi[3/] refined the annual data to areas of 1° longitude by ½° latitude blocks which is the finest areal division possible. Using pair trawl effort, Takahashi computed average density indices (ADI) of pollock by

$$ADI = \sum_{i-1}^{n} \phi'_i / n$$

according to Doi et. al. (1972) where $\phi'_i = c_i/f_i$ = catch per unit effort density index in 1° longitude by ½° latitude statistical block i. The annual average index is then adjusted by an annual modulation factor related to Maeda's (1972) fishing power factor (Table 2) calculated from vessel brake horsepower data.

Low (1974) selected stern trawl fishing effort to compute CPUE for pollock because pollock is also a target species in the continental slopes. However, the fishing power of stern trawls have not increased very much

over the years and adjustments to q need be considered for fishermen skill only. The areal data refinement of Takahashi (see footnote 3) is further grouped to monthly periods. Also, instead of computing CPUE of a gear type and computing total effort by dividing total catch with CPUE of the gear type, total catch and total effort is divided.

To compute total fishing effort, effort of each gear type is standardized and summed over area and time. The fishing effort of each gear type in each 1° longitude by ½° latitude statistical block relative to a certain standard gear type (stern trawl class 8 vessel) is computed by

$$f_{sjk} = P_{ijk} \, f_{ijk}$$

where f_{sjk} = fishing effort standardized to selected standard gear-vessel class (s) at year j in statistical block k

P_{ijk} = relative fishing power to selected standard gear-vessel class for gear-vessel class i, year j, and statistical block k

f_{ijk} = nominal fishing effort for gear-vessel type i, year j, and statistical block k.

Relative fishing powers are computed by Robson's (1966) maximum-likehood technique of estimating relative fishing power of individual vessels. The procedure was programmed by the California Department of Fish and Game (Fox,1971)[4/] and used in the pollock effort analysis. The total amount of fishing effort is merely the sum of all standardized fishing effort. Then, an overall index of pollock abundance in the entire Bering Sea area is computed by dividing total catch with total standardized effort. The alternative mean of ratio estimator of

$$CPUE = \frac{1}{n} \sum_{i=1}^{n} (c/f)_i$$

is not used after testing the variance of catch against effort. A weighted linear regression test shows that the variance of catch is proportional to effort rather than to the square of the effort.

Monthly CPUE indices for pollock are then derived for every month of the years 1964 through 1971. The month of the year when the pollock fishery is operated over the widest expanse in the Bering Sea area for that year is selected to indicate annual CPUE abundance for pollock. This criterion is used because the fishery do not operate in the same areas in the same month from year to year and it is assummed that when the fishery is operated over the widest area, most of the areas within the range of the pollock are being sampled.

Each computed annual CPUE index is later adjusted according to a theoretical learning curve (Fig. 4) assumed to summarize the effects of increasing fishermen skill on q. Since q for the standard stern trawl class 8 vessel is not changed because of no horsepower increase (Takahashi, 1974), such an adjustment according to a learning curve may reflect most of the increase in annual effective effort. When Alton and Fredin (footnote 2) and Takahashi (footnote 3) adjusted effort according to horsepower increases, improvements in trawl design, material, and fish detection electronics are not considered. Also, experience must have improved fishing strategy and efficiency. Although these factors are deemed necessary to adjust for q, their quantification in a learning curve are extremely difficult and always questionable.

All the three procedures of selecting effort attempted to pick representative effort only. Chang (1974) attempted to partition nominal fishing effort to get effective fishing effort by a correlation method. In the procedure, three species (pollock, Pacific Ocean perch, and yellowfin sole) are considered dominant in four gear types (pair trawl, side trawl,

stern trawl, and Danish seine). In a given area and month, let

Y_1 = pollock catch
Y_2 = Pacific Ocean perch catch
Y_3 = yellowfin sole catch
f_1 = pair trawl effort
f_2 = Danish seine effort
f_3 = side trawl effort
f_4 = stern trawl effort

Assume that catches, y, and efforts, f, are normally distributed; partial correlations are computed between y_k and f_m (k = 1,2,3; m = 1,2,3,4) while fixing the effects of other gear type efforts $f_{m'}$ ($m' \neq m$; m' = 1,2,3,4). For instance, $\rho y_1 f_2 (f_1, f_3, f_4)$ is the measure of interdependence between pollock catch and Danish seine effort while the efforts of pair, side and stern trawls are held constant; that is, the coefficient is expressed as the variability of pollock catch and Danish seine effort when the other gear type efforts are constant. The symbols $\rho y_1 f_2 (f_1, f_3, f_4)$ can be expressed as $\rho 12(1,3,4)$ and similarly, for others we have:

Gear	Species: Walleye pollock	Pacific ocean perch	Yellowfin sole
Pair trawl	$\rho 11(2,3,4)$	$\rho 21(2,3,4)$	$\rho 31(2,3,4)$
Danish seine	$\rho 12(1,3,4)$	$\rho 22(1,3,4)$	$\rho 32(1,3,4)$
Side trawl	$\rho 13(1,2,4)$	$\rho 23(1,2,4)$	$\rho 33(1,2,4)$
Stern trawl	$\rho 14(1,2,3)$	$\rho 24(1,2,3)$	$\rho 34(1,2,4)$

The coefficients are interpreted as the vulnerability coefficient or gear efficiency for the k^{th} species by the m^{th} gear type in a given area and time. Effective fishing effort is then calculated by the following relation:

$f'_{ijkm} = \rho_{ijkm} f_{ijm}$

where f_{ijm} = total nominal effort of m^{th} gear over all species in i^{th} area and j^{th} period

f'_{ijkm} = total expected effective effort for k^{th} species with m^{th} gear in i^{th} area and j^{th} period

ρ_{ijkm} = gear efficiency coefficient k^{th} species with m^{th} gear in i^{th} area and j^{th} time period

Table 3 summarizes the differences in the procedures used by Alton and Fredin (footnote 2), Takahashi (footnote 3), Chang (1974), and Low (1974). Results of the CPUE analysis according to the four procedures are shown in Table 4 and Figure 5. It is not unusual that fishing effort analysis has been approached from the standpoint of easy computations because the data base is too large for easy handling. Though it is difficult to select the most accurate procedure, it can be generally accepted that the pollock data should be selected to fine time and area divisions such as by month and statistical blocks.

Other Species

Pollock is such an abundant species in the Bering Sea that the fishery can be viewed upon as a single species system if the areas are carefully delineated. However, for other species that are occasional targets in the overall demersal fisheries, the selection of certain areas by representative gear-vessel types becomes more difficult and less accurate. The yellowfin sole, Pacific ocean perch, and sablefish are targets in some areas: the yellowfin sole by pair trawls in the eastern Bering Sea "flats" (towards the Alaska mainland) and the other two species by longlines and stern trawlers off the Aleutian Islands and the outer continental slope.

Following the procedure of excluding data which fall below an assummed percentile level (Ketchen 1964), catch-effort data in 1° longitude by ½° latitude statistical blocks where yellowfin sole make up 50% or more of the total catch by pair trawls in the eastern Bering Sea "flats" can be grouped for analysis. The data can further be grouped by fishing season according to the spring-summer and winter fisheries for yellowfin sole.

Low[5/] analysed longline data for sablefish in the Aleutian region for the second quarter (April to June) of the year when most of the sablefish are caught for the year in the region. Chikuni (1971) and Low (1974) selected stern trawl fishing data to compute relative stock abundance for the Pacific ocean perch, also in the Aleutian region.

In the analysis of CPUE for these occasional target species, only index areas by time period have been chosen to indicate relative stock abundances. There are other areas and time periods when these species are caught incidentally to pollock in considerable amounts. The yellowfin sole is also caught in the outer continental shelf areas where pollock predominates. Large amounts of sablefish and Pacific ocean perch are caught by stern trawlers off the continental slopes where pollock also predominates. In the Aleutian CPUE index area, Pacific ocean perch is landed by longlines as well as by large stern trawlers. All these fish caught in non-index areas and time by non-index gear types are important but yet have to be necessarily left out in determining relative stock abundance.

As the species becomes less abundant and important in the multi-species, gear-time-area index for CPUE analysis becomes more difficult to find.

Non-target Species

Many of the minor species make up less than one percent of the overall catch on the average. For such species where no definable areas or time periods can be singled out year after year as specific fishing areas for these species, there is no simple way for selecting representative gear-vessel types. For example, the rock sole, Lepidopsetta bilineata; flathead sole, Hippoglossoides elassodon; and arrowtooth flounder, Atheresthes stomias, seldom are target species and relatively low in abundance where the main fishery operates.

Since these species are incidentally caught in the yellowfin sole fishery, it may be true that CPUE of any gear type effective for flatfish may be more representative of the species abundance because the samples may be more random. However, the commercial fisheries are selective for yellowfin sole in the same area and unless more is known about these minor species distribution and mixing with yellowfin sole, it is difficult to comment on their relative stock status. Also, since the abundance is so low in the overall catch, the single species concept of CPUE is probably less applicable. Consequently, the pooled species approach may be applied.

The pooled species approach lack individual species details and though the single species approach of CPUE analysis is questionable, the latter approach gives a rough idea of relative abundance between different species. The data are usually screened to eliminate effort with zero catch and CPUE is determined simply by directing total catch with effort. When interpreting CPUE indices for these minor species, effort devoted to catch the major species should be kept in mind.

DISCUSSION AND CONCLUSION

Catch per unit of effort (CPUE) derivation is the first step in many subsequent population dynamics analysis. The catch-effort data may be used to estimate maximum sustainable yield from generalized surplus production models (Schaefer, 1957; Pella and Tomlinson, 1969). Together with age-length data, the relative strength of year classes may be derived. Mortality rates may be determined and with weight data, yield per recruit analysis (Beverton and Holt, 1957) may then be conducted. These are some of the analyses that have been carried out for the Alaska pollock fishery.

It is important that the two fundamental catch-effort statistics be accurate and consistent for comparison by area and time. The statistics on catch is ignored in this paper. It has a standard unit of measurment and fish catch is assumed accurate. On the other hand, effort unit has no standard. The effective level of effort to catch a certain species is changed by a number of factors which may not be parametized. The four procedures of analysis on pollock are by no means complete and accurate. To achieve the best result, the commercial catch-effort data base should be screened carefully to eliminate data by gear, time, and area where a certain species is definitely not found. It is practical to aggregate data to 1° longitude by $\frac{1}{2}$° latitude statistical blocks by month and gear type. As much as possible, factors that change the catchability coefficient, such as technological change and learning ability, should be considered to adjust fishing effort.

Although CPUE indices may be indicative of actual stock abundance for major target species, additional information on the biological statistics of the fish should be considered to augment CPUE interpretations. There is

no proper procedure, but only convenient ones, to derive CPUE of minor species in the Bering Sea multi-species fishery.

Interactions between species are important in the demersal community, but the community is such a complex system that simplification to a single-species or a pooled species approach of analysis are the only practical alternatives. With today's computing power, it is possible to postulate species interactions in a fish ecosystem model to study the dynamics of the stocks. Such a model being conceived, may not answer specific questions required for management purposes but should direct research priorities with a better perspective of the Bering Sea system.

Finally, the problems of determining relative stock density in the Bering Sea multiple species situation are very similar to those encountered in the Atlantic and elsewhere. Although the Bering Sea CPUE excercises, like in other fisheries, may not have anything new to contribute to stock abundance assessments since the 1950's, they nevertheless illustrate the importance of standardizing fishing effort and the most practical means of gauging stock size trends. The fishing power of the effort expanded by the fishery simply cannot be equated from year to year as the fishing processes mature with time. One must pay special attention to technological improvements and learning processes, especially to well organized fleets.

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FOOTNOTES

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5/ Low, L. L. 1974. Status of sablefish resources in the Bering Sea. U.S. Dep. Commer., Natl. Oceanic Atmos. Admin., Natl. Mar. Fish. Serv., Northwest Fish. Center, Seattle, Wash., 19 p., unpubl. rep.

Table 1.--Catch of walleye pollock by gear type in the Japanese mothership and North Pacific trawl fisheries in the Bering Sea, 1964-73.

Gear type	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Danish seine	138,492	176,453	129,526	253,971	326,319	353,107	445,588	362,425	312,959	228,306
Pair trawl	33,790	44,321	60,852	137,481	167,600	153,980	367,811	485,604	635,950	538,379
Side trawl	2,525	5,553	66,643	51,319	11,428	14,845	4,622	-	-	-
Stern trawl	514	1,430	6,979	103,506	161,838	319,048	384,873	634,101	700,151	725,579
Others	2	-	-	-	-	-	-	-	-	-
Total Catch	175,520	227,973	264,757	548,487	671,303	841,774	1,203,247	1,491,409	1,649,565	1,492,263

Data source: Takahashi (see text footnote 3)

Table 2.--Average density index (ADI) of abundance of walleye pollock in the Bering Sea, 1964-73 (after Takahashi, see text footnote 3).

	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Fishing power by Maeda (1972)	8.44	8.44	9.34	9.86	12.74	15.90	16.98	20.10	20.80	-
Modulation factor	.66	.66	.73	.77	1.00*	1.25	1.35	1.58	1.63	1.74**
ADI	5.65	6.13	5.00	6.37	11.84	12.99	11.99	9.13	15.24	10.87
Adjusted ADI by modulation factor	8.53	9.25	6.83	8.23	11.84	10.41	9.00	5.79	9.33	6.25

*1968 vessels chosen as standard.
**Estimated by Takahashi (1974).

Table 3.--Procedures of analysis of fishing effort on walleye pollock that have been used by different scientists.

Procedures	Takahashi [1]	Alton and Fredin [2]	Low (1974)	Chang 1974
Multi-national data source				
Selected Japanese data	*	*	*	*
Adjust analysis to catch by all nations	X	*	*	X
Multi-species				
Single species analysis	*	*	*	*
Pooled species analysis	X	X	*	X
Data stratification				
1. By area				
Summed over 5 large areas	X	*	X	X
Summed over 2 large areas	X	X	X	*
Summed over more than 80 statistical blocks of 1° longitude by ½° latitude	*	X	*	X
2. By Time periods				
Annual scale	*	*	X	*
Monthly scale	X	X	*	X
Fishing effort Analysis				
1. Effort by species				
Selected representative gear	*	*	*	X
Partitioned effort of gear	X	X	X	*
2. Catchability coefficient adjustment				
with vessel horsepower	*	*	*	X
with a learning curve	X	X	*	X
3. Total effort				
Total catch by all nations	*	*	X	X
Sum of (effort x relative fishing power)	X	X	*	*

* Procedure followed
X Procedure not followed

1/ See text footnote 3.
2/ See text footnote 2.

Table 4.--Values of relative abundance--of the Bering Sea stock of pollock--that have been estimated by different scientists using different procedures.

Source	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Takashi [1]	8.53	9.25	6.83	8.23	11.84	10.41	9.00	5.79	9.33	6.25
Alton and Fredin [2]	9.52	18.34	24.04	21.73	24.00	31.78	18.78	15.24	14.50	
Low (1974b) [3]	6.46	8.48	4.74	6.67	6.50	7.28	5.73	5.99		
Chang (1974) [4]	2.72	4.80	4.40	7.09	7.67	7.79	13.10			

1 See text footnote 3; tons per modulated pair trawl hour.

2 See text footnote 2; tons per thousand pair trawl-horsepower hours.

3 Tons per adjusted stern trawl hour.

4 Tons per effective pair trawl hour.

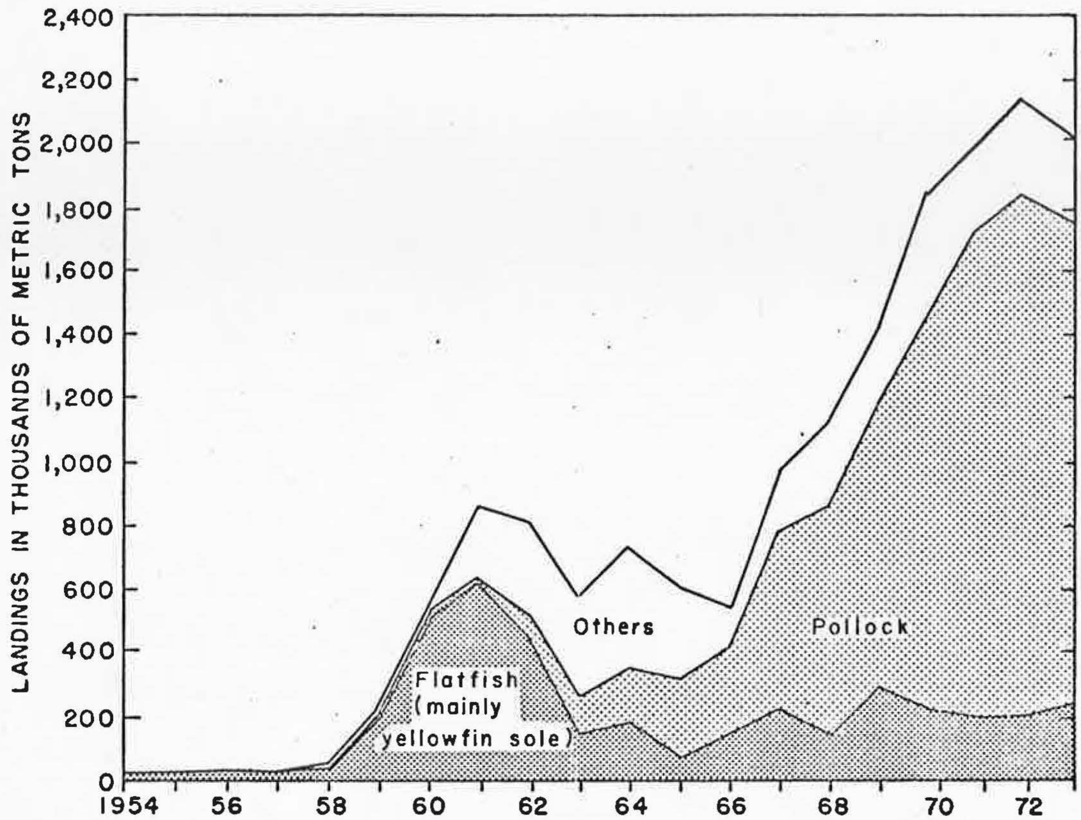

Figure 1. Estimated landings of flatfish, pollock, and other bottomfish by all nations from the Bering Sea, 1954-73.

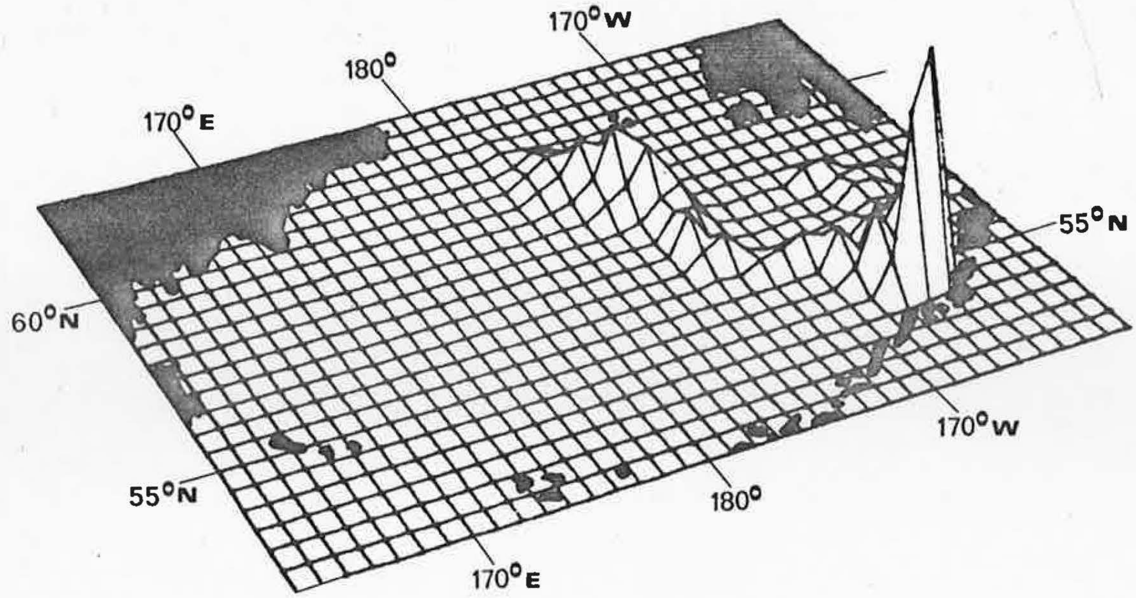

Figure 2. Example of a three-dimensional graph depicting fish caught by area, time and gear-vessel type in the Bering Sea.

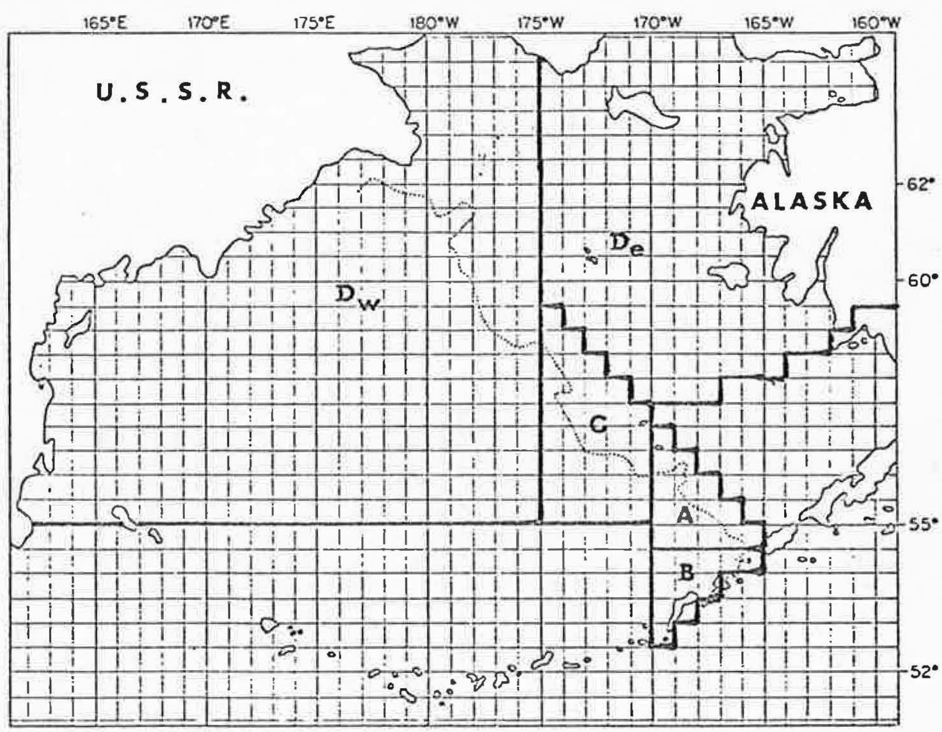

Figure 3. Map of locations of Bering Sea areas partitioned by the following scientists for analysis of fishing effort on pollock: (a) Alton and Fredin (see text footnote 2) into areas A to D, (b) Takahashi (see text footnote 3) and Low (1974) into degree longitude by half degree latitude blocks, and (c) Chang (1974) into areas east and west of 170°W longitude.

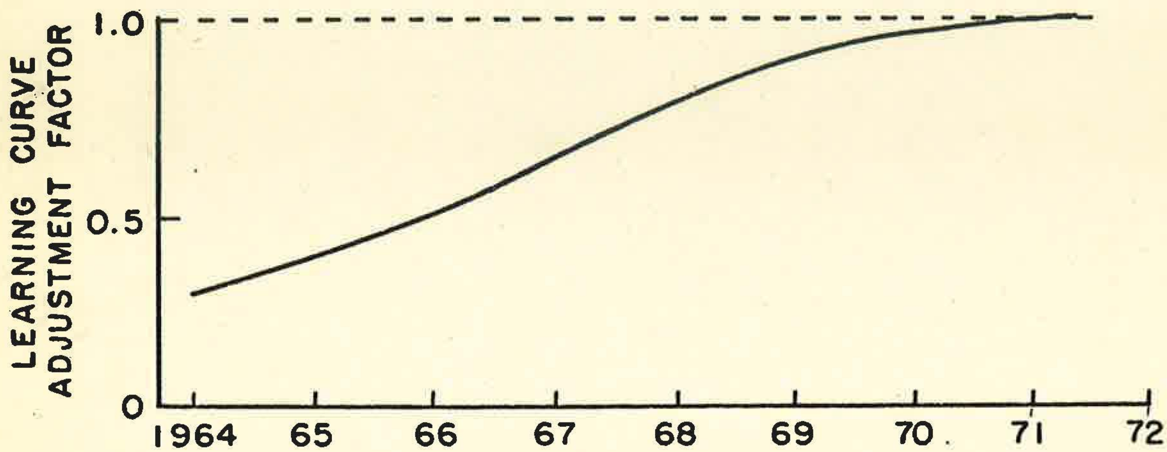

Figure 4. A theoretical learning curve depicting fishing power increase with time for the Bering Sea, 1964-72.

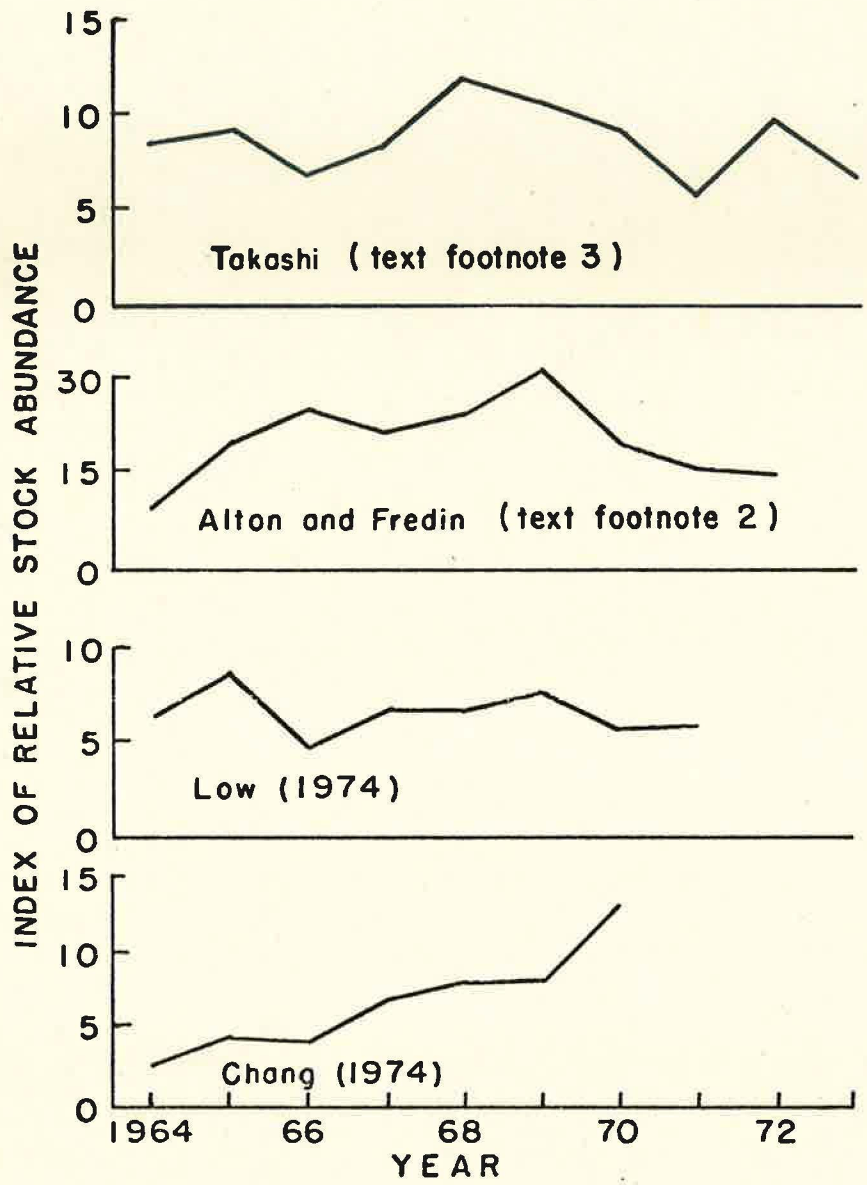

Figure 5. Curves showing annual relative abundance--of the Bering Sea stock of pollock--that have been estimated by different scientists using different procedures.