# An Analysis of the Catch Records of the Alaska Pollack Trawling-I*

## The Seasonal Changes of the Bathymetric Distributions of the Catch per Haul, the Number of Hauls, and the Towing Time

By
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The landing of the Alaska pollack showed a remarkable and rapid increase in the last decade, and occupied about as much as 30% of the yearly total of the landing in 1970 by the Japanese fleets. And most of the landing, especially its recent increase, was mainly brought from the Bering Sea by the two types of fisheries. One is the fleet type. A fleet usually consists of 10 to 20 Danish seiners and several pairs of bull trawlers both supplying the factory ship with the catch as the material of the minced fish. The other is the stern ramp trawling capable of catching and processing the fish without any other supporting systems. The changes of the amount of daily catch[1),3),4)] and the working speed [2)] of the Danish seiners of the former type of fishery were examined in the preceding two series of reports. The following restrictions, however, made it hard to examine in detail the influence of the working conditions on the amount of catch and on the working speed. First, the fishable depth was legally restricted within 150 m, in spite of the facts that the objective fish is distributed to far deeper grounds and the boats are constructed suitable for fishing in far deeper grounds than this depth. This fact, on one hand, made it hard to find any clear pattern of the bathymetric distribution of the objective fish, and on the other hand, made it hard to examine the difference of the working speed due to the difference of the depth of the fishing grounds and due to the power difference of the boats. Second, the working hours were restricted from a little before the sunrise to a little after the sunset, in spite of the fact that the length of the daytime in such a high latitudinal water as this (55° to 60° N) shows a large seasonal change. This fact made it hard to examine not only the daily rhythmic change of the catch pattern but also the different suitability of the boats due to the different work pattern from the point of view of the labor administration throughout the long season. Third, the season was restricted within the

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period from April to September. This made it hard to examine the seasonal change of the catch pattern. Fourth, the boats could not work independently of the factory ship. This restricted the boats in many of the respects. The boats had to fish in the ground wider than the area covered by all the fellow boats, and the high concentration of fish in a narrow spot was out of the objective of the fleet operation. And the boats should choose their fishing point taking those of the other fellow boats into consideration. The behavior of the boats received also the interference of the other fellow boats — either assisted or disturbed. And the fishing work of the boats was interrupted by the trans-shipping work of the catch to the factory ship. But it was hard to separate the influence of these facts from that of the factors under consideration.

In contrast with the fleet operation, the stern ramp factory trawling is free from most of the above-mentioned restrictions and obstructions. And its catch records are suitable for the examination on the seasonal and daily rhythmic change of the bathymetric distribution of the objective fish. Namely, the stern ramp factory trawlers are free from the legal restrictions of the fishing season and the fishing grounds. They work day and night throughout the year. They can work without the interference of the fellow boats, and a high concentration of the objective fish in a narrow spot is the good objective.

The other fact making the catch records of the stern ramp trawling of this type suitable for the analysis of the distribution of the objective fish is that the boat of this type aims at the single species of fish regardless of the density of the other salable fish because of the construction of her processing plant, although even the catch records of this type of fishery are not free from the problems derived from the basic nature of the fishing method and those derived from the basic nature of the records during the commercial fishing. Usually, the stern ramp trawlers aiming the groundfish as the material of the frozen products choose their main objectives according to not only the distribution and relative abundance of the groundfish complex but also their relations to the economic and administrative factors. And the fluctuation of the amount of catch of a single species does very frequently not show that of the relative abundance; but it is hard to neglect the fluctuation of the catch of the other salable fish. The modification like this is serious when the species under consideration is neither the prime fish nor the abundant one. And the fluctuation of the market demand by species, that of the catch by the fellow boats, and the space of the fish hold to be filled and its relation to the working schedule including that of the transporters, are the group of the factors making the boats change their main objective species, besides the relative abundance of the species under consideration. And it is hard to separate the influences of the biological factors from those of the administrative ones. This makes the analysis complicated. But the large stern ramp trawler of the type examined here aims exclusively at a single species, the Alaska pollack, because of the construction of her processing plant. The catch records of this type of fishery are, accordingly, free from the influence of these administrative factors, and are suitable for the analysis on many of the biological problems and working ability of the boats.

One of the most remarkable advances in the fishing techniques in these days is the popularization of the electronic supporting devices. This caused a basic change in the details of the fishing method, consequently in the results, i.e. in the relation of the amount of catch per haul to the other factors. In the present series of reports, the catch records of a large stern ramp factory trawler processing the Alaska pollack into the minced fish were analyzed, with an intention of showing the change of the amount of catch according to the conditions. The other aims of the present series were to show the difference between the meanings of respective items in the catch records of the modern trawling and those of the traditional one and to show a trial of how to take the influence of these facts into consideration during the analysis. And as the first step of the analysis, an outline of the bathymetric distributions of the amount of catch per haul, the number of hauls, the length of towing time, and their seasonal changes observable in the case taking the influence of the other factors into no account were shown in the present report.

## Material and Method

There were two types of fisheries catching mainly the Alaska pollack along the outer edge of the continental shelf of the Bering Sea and processing it into the minced fish. They were the fleet type and the single large stern trawler one. The former type of fishery was initiated in the early part of 1960's; while the latter type was developed quite recently, and its first boat (about 4,000 gross tons) started to fish in November and the second boat in December of 1968. The materials used in the present series of reports were the working records on the 3,132 hauls conducted during the first three trips of the second boat (the first trip being from Dec. 23,'68 to May 23, '69, the second trip from June 22 to Nov. 26 of 1969, and the third trip from Dec. 25, '69 to May 2, '70).

The original records used here included the data on the following items. They were similar to those of the working records of the traditional trawling, but the facts indicated by some of them differed completely from those of the traditional one. They were the date, the position fished, the hour starting to shoot the gear, the hour starting to haul up the gear (to wind up the warp), the length of the time towing the gear, the towing course, the towing speed, the revolution of the main engine during towing, the depth fished, the length of warp paid out, the height of net mouth, the amount and the composition of the catch, some oceanographic and meteorological conditions, the time spent in finding out the echo from the presumably profitable school, and the description on the echogram observed. Among them, the present report dealt with the relations among the amount of catch, the depth fished, and the length of towing time.

The principal objective of this boat was the Alaska pollack; but there were many hauls yielding noticeable amount of the other species than the Alaska pollack——for examples, the Pacific cod, the rockfishes, and the pleuronectids. Either when the boat yielded continuously very good catch and the fish pond was filled with the material fish carried over or when there occurred some troubles in the processing plant, the boat

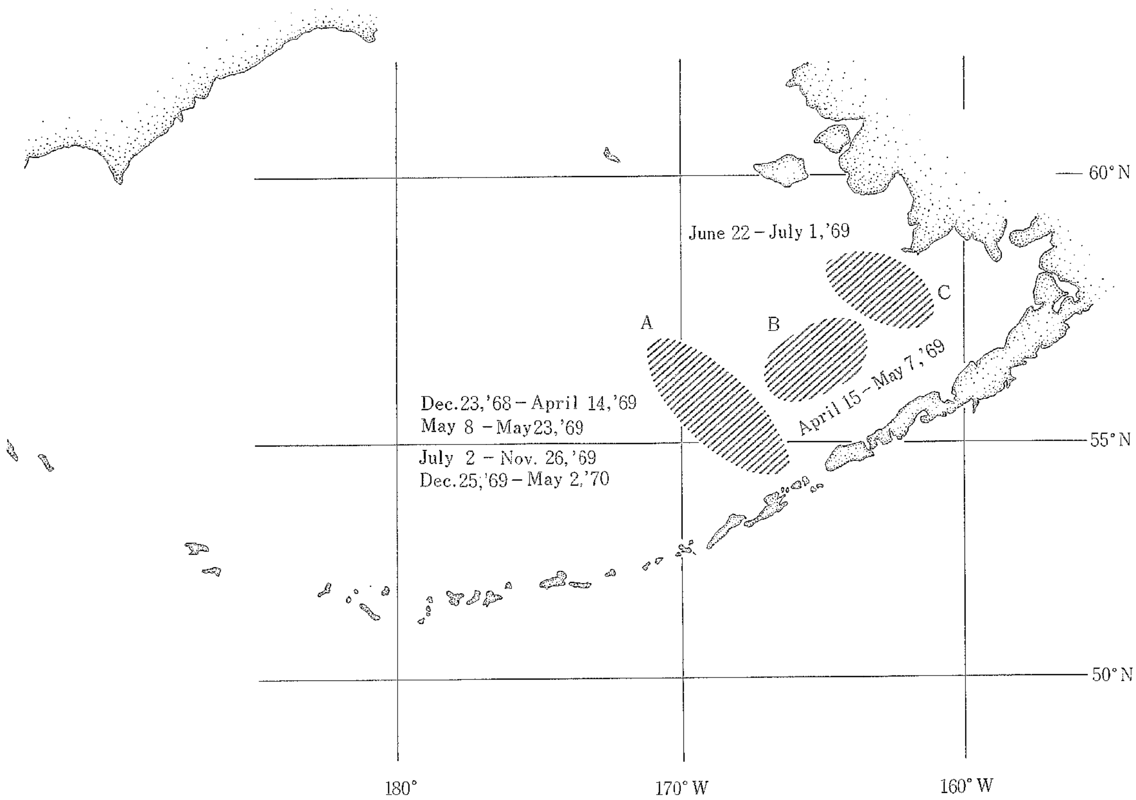


Fig. 1. The location of the fishing grounds of the trawler examined here.

aimed at these fishes as the materials of the frozen products either headed or filleted. In the other cases, they were caught incidentally and the presence of them disturbed very much the smooth work or needed much additional hands, because they should be soated out for the purpose of uniformizing the quality of the minced fish produced. The other fish than the Alaska pollack occupied more than 10% of catch in the 342 hauls. The records on these hauls were excluded from the examinations, because whether these fish were caught purposively or incidentally depended on many conditions and it was practically hard to examine the records case by case. The gear was broken seriously during the 54 hauls. The records on these hauls were also excluded. In consequence, the records on the 2,736 hauls were used in the present report.

The amount of catch by a haul ranged from 0 to 60 tons. When the catch was poorer than 10 tons, the recorded amount inclined to take the value of 2, 3, 5, 7, or 8 tons. Namely, the catch was measured mainly in 2.5-ton intervals, then its decimal part was either cut away or raised to a unit, and it was described in tons. When the catch was better than 10 tons, it was described chiefly in 10-ton intervals and rarely in 5-ton intervals. The recorded values were, accordingly, aggregated into the classes of 10-ton intervals and used in the present report.

The echo-sounded depth just before shooting the gear ranged from 25 m to 500 m. The recorded depths were aggregated into the zones of 25-m intervals and used in the present report, because the range and the accurracy of the depth measuring were taken into account. Sometimes, the boat towed her gear along a sloap. When the difference between the depths just before shooting and hauling the gear exceeded 25 m, the average of them was used in stead of that just before shooting. The length of towing time was recorded in minutes and ranged from 15 minutes to more than three hours. The recorded values were aggregated into the classes of 5-minute intervals and used in the present report, because the range and the accurracy of the time measuring were taken into account.

Besides them, many other factors either probable to have a close relation to the distribution of the objective fish or probable to have a close relation to the fishing efficiency of the boat were described in the original records. And the influence or modification of the results due to these factors will be shown in the succeeding reports.

## Results and Considerations

### 1. The type of the frequency distribution of the amount of catch by a haul

The type of the frequency distribution of the amount of catch by a haul is one of the most important characteristics of the catch pattern not only because this provides us with many clues to conjecture the outline of the distribution pattern of the objective fish but also because the observed values of the amount of catch should be used in the further examination after the transformation according to the agreeable type, if the distribution is not agreeable to the normal distribution.

It is a well-known fact that the distribution of the groundfish depends on the depth and differs according to the season. And it is probable that the density and the distribution pattern differs according to the location fished. The records were, accordingly, stratified into the month-depth (100 m intervals) -ground groups. Then, for the 29 groups of the records with more than 25 hauls thus classified, whether the observed series of the frequency distribution of the amount of catch by a haul ( $x$ tons ) was agreeable to the normal distribution or not was examined. But, in some of the groups of the records in winter months, the distribution showed a bias of the mode in the direction of the class of poor catch. And in some of those in the other seasons, the distribution showed a bias of the mode in the direction of the class of good catch. For the groups of the records in the former type, the value of $a$ making the normal deviate—$\log(x+a)$ relation in a straight line was sought with the assistance of the logarithmic probability paper. And for the groups of the latter type, the value of $b$ making the normal deviate — $\log(b-x)$ relation in a straight line was sought. Then, the observed distributions were compared with the Gibrat ones, after the transformation of $x$ into either $(x+a)$ or $(b-x)$.

The comparison of the results of these tests of the fitness to either of the theoretical

distributions showed the following facts:
1) The observed distribution in the 20 groups out of the 29 ones fit the normal distribution. And in the 18 groups out of these 20 ones, the better result was obtained when the observed distribution was compared with the normal one than when compared with the Gibrat one.
2) The observed distribution in the other three groups did not fit the normal distribution but fit the Gibrat one after the $(x+a)$ transformation. In one of the groups fitting the normal distribution, the better result was obtained when the observed distribution was compared with the Gibrat one than when compared with the normal one.

Table 1. The observed series of the frequency distribution of the hauls in respect of the amount of catch and the results of the test on the fitness to either the normal series or the Gibrat one.

| Month | Feb. '69 | | April (A) '69 | | May (A) '69 | | Jan. '69 | | |
|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | 225–300 | | 325< | | 225–300 | | 225–300 | | |
| Type | Ob. | Normal | Ob. | Normal | Ob. | Normal | Ob. | Normal | $\log(x+10)$ |
| Catch class (tons) 0 | 2 | 7.73 | 0 | 0.18 | 2 | 2.15 | 1 | 5.45 | 0.60 |
| 10 | 23 | 18.82 | 4 | 3.85 | 10 | 9.25 | 11 | 9.63 | 12.37 |
| 20 | 36 | 31.86 | 21 | 20.59 | 21 | 20.11 | 23 | 14.63 | 19.41 |
| 30 | 29 | 30.89 | 28 | 28.78 | 17 | 20.10 | 10 | 14.34 | 13.17 |
| 40 | 16 | 17.15 | 11 | 10.58 | 11 | 9.25 | 7 | 9.08 | 6.73 |
| 50 | 7 | 5.45 | 1 | 1.02 | 2 | 2.14 | 5 | 3.71 | 3.12 |
| 60 | | 1.10 | | | | | 1 | 1.16 | 2.60 |
| $\chi_0^2$ | | 5.94 | | 0.04 | | 0.78 | | 7.47 | 1.52 |
| df | | 3 | | 1 | | 1 | | 2 | 2 |
| Prob. | | 0.25–0.10 | | 0.90–0.75 | | 0.50–0.25 | | 0.025–0.01 | 0.50–0.25 |

| Month | Feb. '70 | | | July '69 | | | Oct. '69 | | | March '70 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Depth (m) | 225–300 | | | 225–300 | | | 225–300 | | | 225–300 | | |
| Type | Ob. | Normal | $\log(x+20)$ | Ob. | Normal | $\log(60-x)$ | Ob. | Normal | $\log(60-x)$ | Ob. | Normal | $\log(70-x)$ |
| Catch class (tons) 0 | 1 | 1.03 | 0.06 | 4 | 3.51 | 4.56 | 6 | 5.56 | 7.28 | 0 | 0.26 | 0.59 |
| 10 | 9 | 9.29 | 8.38 | 19 | 20.77 | 16.28 | 25 | 27.93 | 22.16 | 3 | 2.33 | 2.20 |
| 20 | 31 | 31.12 | 38.44 | 50 | 55.40 | 49.98 | 55 | 51.79 | 49.07 | 7 | 9.51 | 8.13 |
| 30 | 40 | 37.53 | 34.66 | 73 | 62.64 | 76.76 | 33 | 33.56 | 41.99 | 20 | 16.64 | 18.59 |
| 40 | 14 | 16.34 | 12.88 | 33 | 30.05 | 30.63 | 8 | 7.56 | 6.47 | 16 | 12.56 | 15.11 |
| 50 | 3 | 2.69 | 2.96 | | 6.09 | 0.79 | | 0.60 | 0.03 | | 4.09 | 1.38 |
| 60 | | | 0.62 | | 0.54 | | | | | | 0.61 | |
| $\chi_0^2$ | | 0.39 | 2.57 | | 9.38 | 0.79 | | 0.55 | 3.58 | | 1.50 | 0.29 |
| df | | 1 | 1 | | 3 | 2 | | 2 | 2 | | 1 | 1 |
| Prob. | | 0.75–0.50 | 0.25–0.10 | | ≒ 0.025 | 0.75–0.50 | | 0.90–0.75 | 0.25–0.10 | | 0.25–0.10 | 0.75–0.50 |

Note: Ob ..... Observed series Normal ..... Normal series
$\log(x+a)$ or $\log(b-x)$ ..... The Gibrat series after either the $(x+a)$ or the $(b-x)$ transformation
$x$ ..... The amount of catch in tons (10-ton intervals)
df ..... The degree of freedom for the chi square value

3) The same results were obtained in the comparison of the results of the test on the fitness to the normal distribution with those to the Gibrat one after the ( $b-x$ ) transformation.
4) The observed distribution in the three groups of the rest fit neither the normal one nor the Gibrat one.

Table 2. The results of the test of the fitness of the observed series of frequency distributions of the hauls in respect of the amount of catch either to the normal series or to the Gibrat one after the transformation of $x$ into $x'$.

| Area | Month | Depth range (m) | Normal | | | Gibrat | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | $\chi_0^2$ | df | Prob. | $x'$ | $\chi_0^2$ | df | Prob. |
| A | Jan. '69 | <200 | 49.74 | 3 | 0.005> | ( $x+10$) | 21.56 | 3 | 0.005> |
| | | 225—300 | 7.47 | 2 | 0.025—0.010 | ( $x+10$) | 1.52 | 2 | 0.500—0.250 |
| | Feb. | 225—300 | 5.94 | 3 | 0.250—0.100 | | | | |
| | | 325< | 0.82 | 1 | 0.500—0.250 | | | | |
| | March | 225—300 | 0.11 | 1 | 0.750—0.500 | | | | |
| | | 325< | 0.91 | 2 | 0.750—0.500 | | | | |
| | April | 325< | 0.04 | 1 | 0.900—0.750 | | | | |
| B | April | 100—125 | 0.45 | 1 | 0.750—0.500 | | | | |
| | May | 125 | 1.80 | 1 | 0.250—0.100 | | | | |
| A | May | 225—300 | 0.78 | 1 | 0.500—0.250 | | | | |
| C | | <100 | | | | ( $x+10$) | 0.002 | 1 | 0.950—0.900 |
| A | July | 225—300 | 9.38 | 3 | ≒0.025 | (60— $x$ ) | 0.79 | 2 | 0.750—0.500 |
| | | 325< | 1.48 | 1 | 0.250—0.100 | (60— $x$ ) | 0.09 | 1 | 0.900—0.750 |
| | Aug. | <200 | 6.52 | 1 | 0.025—0.010 | (60— $x$ ) | 3.68 | 1 | 0.100—0.050 |
| | | 225—300 | 0.37 | 2 | 0.900—0.750 | (60— $x$ ) | 8.50 | 2 | 0.025—0.010 |
| | Sept. | 225—300 | 10.42 | 2 | 0.010—0.005 | (60— $x$ ) | 23.00 | 2 | 0.005> |
| | | 325< | 1.76 | 1 | 0.250—0.100 | (60— $x$ ) | 1.39 | 1 | 0.250—0.100 |
| | Oct. | 225—300 | 0.55 | 2 | 0.900—0.750 | (60— $x$ ) | 3.58 | 2 | 0.250—0.100 |
| | | 325—375 | 0.31 | 2 | 0.900—0.750 | (60— $x$ ) | 0.92 | 1 | 0.500—0.250 |
| | Nov. | 225—300 | 1.18 | 1 | 0.500—0.250 | (60— $x$ ) | 1.79 | 1 | 0.250—0.100 |
| | Jan. '70 | <200 | 8.80 | 2 | 0.025—0.010 | ( $x+20$) | 2.20 | 2 | 0.500—0.250 |
| | | 225—300 | 1.14 | 1 | 0.500—0.250 | ( $x+20$) | 0.11 | 1 | 0.750—0.500 |
| | Feb. | 225—300 | 0.39 | 1 | 0.750—0.500 | ( $x+20$) | 2.57 | 1 | 0.250—0.100 |
| | | 325—400 | 0.19 | 1 | 0.750—0.500 | ( $x+20$) | 1.34 | 1 | 0.250—0.100 |
| | March | 225—300 | 1.50 | 1 | 0.250—0.100 | (70— $x$ ) | 0.29 | 1 | 0.750—0.500 |
| | | 325—400 | 21.19 | 2 | 0.005> | (70— $x$ ) | 16.11 | 2 | 0.005> |
| | April | 125—200 | 2.09 | 2 | 0.500—0.250 | | | | |
| | | 225—300 | 0.79 | 2 | 0.750—0.500 | | | | |
| | | 325—400 | 3.09 | 1 | 0.100—0.050 | | | | |

The frequency distributions of the amount of catch in most of the groups of the records were, thus, agreeable to the normal ones. And it was hard to find any theoretical distribution commonly agreeable to the observed ones in all or most of the groups of the rest. For the purpose of making it possible to examine the bathymetric and seasonal change of the amount of catch per haul, accordingly, the recorded values after the aggregation into the classes of 10-ton intervals were used in the further analysis without any transformation.

## 2. The bathymetric change of the amount of catch per haul

It is a well-known fact that the depth is one of the factors having a very close relation to the distribution of the groundfish, although the preferable depth differs according to the species and season. And the density of a species is highest on the bottom of a certain depth and decreases in accordance with the depth difference from this zone. In the traditional trawling, the skippers decide the location ( or depth ) to shoot the gear basing on their long experience and the results of the preceding hauls. Some of the hauls yield poor catch because the depths fished are either too shallow or too

Table 3. The regression equations of the amount of catch per haul ( $y$ in tons ) on the depth fished ( $x$ in meters ) and the results of their significance test.

| Month | $a_0$ | $a_1$ | $a_2$ | $F_{2\cdot1}$ | $F_{2\cdot2}$ | $b_0$ | $b_1$ | $F_{1\cdot1}$ | $n$ |
|---|---|---|---|---|---|---|---|---|---|
| Dec. '68 | 36 | −0.08 | −0.00002 | 0.05 | 0.00 | 37 | −0.09 | 3.93 | 36 |
| Jan. '69 | 7 | 0.13 | −0.0002 | 0.42 | 0.22 | 16 | 0.04 | 3.88 | 195 |
| Feb. | −46 | 0.46 | −0.0008 | 9.11** | 6.78* | 5 | 0.07 | 13.11** | 164 |
| March | −13 | 0.19 | −0.0002 | 0.84 | 0.50 | 5 | 0.13 | 8.17** | 212 |
| April (A) | 43 | −0.17 | 0.0003 | 0.14 | 0.27 | 6 | 0.03 | 7.05** | 78 |
| April (B) | 8 | −0.08 | 0.0020 | 0.00 | 0.00 | −17 | 0.37 | 21.61** | 116 |
| May (A) | −41 | 0.57 | −0.0012 | 9.43** | 10.48** | 29 | −0.02 | 0.75 | 86 |
| May (B) | − 4 | 0.72 | −0.0068 | 0.71 | 1.21 | 24 | −0.20 | 1.18 | 27 |
| July | 15 | 0.06 | −0.0001 | 0.08 | 0.03 | 20 | 0.02 | 1.37 | 219 |
| Aug. | 24 | −0.002 | 0.00001 | 0.00 | 0.00 | 23 | 0.002 | 0.02 | 230 |
| Sept. | 26 | 0.36 | −0.0006 | 3.46 | 3.27 | 20 | 0.01 | 0.38 | 235 |
| Oct. | −15 | 0.23 | −0.0004 | 0.75 | 0.60 | 14 | 0.03 | 1.99 | 209 |
| Nov. | −34 | 0.41 | −0.0007 | 6.12* | 4.08* | 2 | 0.08 | 13.88** | 135 |
| Dec. | 277 | −2.97 | 0.0082 | 5.22* | 5.75* | −11 | 0.14 | 2.48 | 20 |
| Jan. '70 | 32 | −0.13 | 0.0003 | 0.94 | 1.24 | 17 | 0.02 | 1.31 | 158 |
| Feb. | 4 | 0.12 | −0.0002 | 4.10* | 2.66 | 18 | 0.03 | 4.98* | 161 |
| March | −45 | 0.46 | −0.0007 | 5.20* | 5.60* | 36 | −0.02 | 0.79 | 202 |
| April | 35 | −0.14 | 0.0003 | 2.14 | 2.40 | 20 | 0.01 | 0.34 | 200 |

Note: $y = a_0 + a_1x + a_2x^2$
$y = b_0 + b_1x$
$F_{ij}$ . . . . . The Snedecor's $F$ value of the $j$-th order regression coefficient in the $i$-th order equation, with 1 and $(n-i-1)$ degrees of freedom
$n$ . . . . . Size of samples
* significant at 0.05 level ** significant at 0.01 level
The letter in parenthesis is the abbreviation of the area shown in Fig. 1.

deep to yield a good catch. And the most profitable depth zone, i.e. the depth of the highest density, is found as the results of the trial and error. The work pattern like this makes it possible to conjecture the bathymetric change of the relative abundance of the objective fish from that of the amount of catch per haul. But whether it was possible to find the bathymetric change of the relative abundance of fish through the catch records of the modern trawling or not was doubtful, because of the following difference of the work pattern due to the good use of the electronic supporting devices: In the modern trawling, the bottom topography and the distribution of the objective fish are examined before shooting the gear. And only the schools of presumably profitable size are attacked selectively. The work pattern like this saves the boat from less profitable towing. During the towing, the tension meter shows unintermittently the change of the load on the warp, and the net sonde records the change of the height of the net mouth and the echo from the objects passing through the space

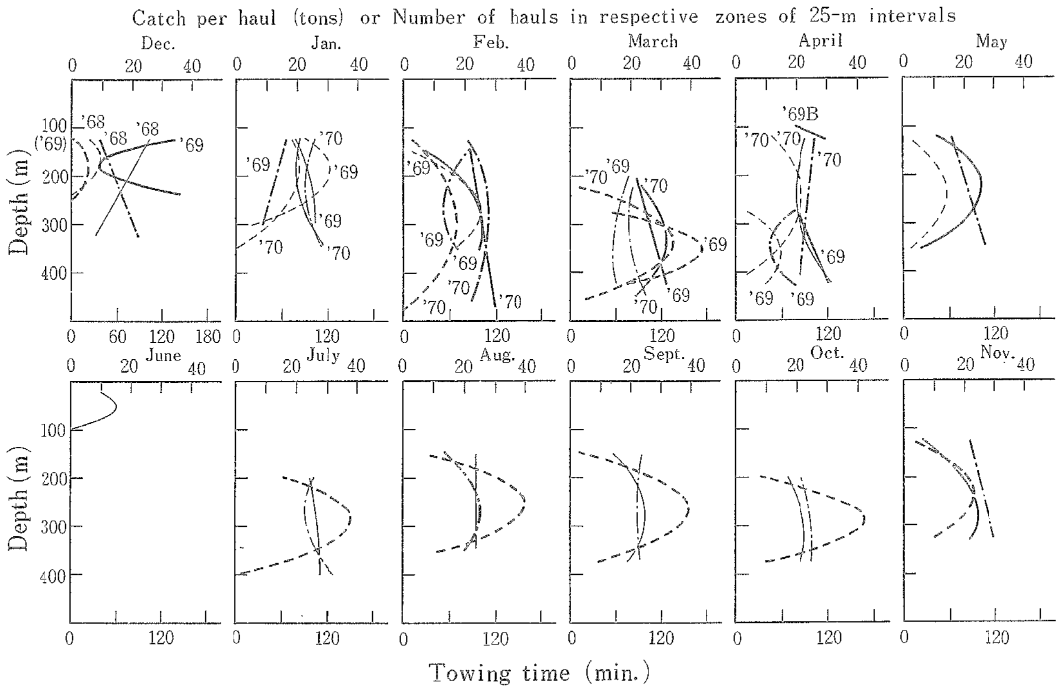


Fig. 2. The bathymetric distributions of the amount of catch per haul, the number of hauls, and the length of towing time.

Note: The regression equations illustrated in this figure are shown in Tables 3,4, and 5. All the relations in May to November are for 1969.

Solid line ..... The amount of catch per haul ( in tons, the upper abscissa )

Broken line ..... The number of hauls conducted in respective depth zones of 25-m intervals ( the upper abscissa )

Chain line ..... The length of towing time per haul ( in minutes, the lower abscissa )

Thick curve ..... The regression curve with the significant quadratic coefficient

Thick line ..... The regression line with insignificant quadratic coefficient but the significant linear one

Thin curve ..... The regression curve with neither the significant quadratic coefficient nor the significant linear one between the head rope and the sea bed. And the time to haul up the gear is decided basing on the informations from these devices. The work pattern like this makes the boat yielding an equal amount of catch by a haul rather regardless of the density of the fishable population.

When the amount of catch per haul shows a maximum from the bottom of an intermediate depth and decreases in accordance with the depth difference from this zone, the simplest representation of the bathymetric distribution of the amount of catch per haul may be the quadratic equation. And whether the relation like this was observable in the catch records of the modern trawling or not was, accordingly, examined through the significance test of the quadratic coefficient in the quadratic regression equation of the amount of catch per haul on the depth fished, and the significance test of the linear coefficient in the regression line was added, for reference. The results shown in Table 3 revealed the following facts: Only the four month-ground groups of the records out of the 18 ones showed the significant quadratic regression with the maximum catch per haul at an intermediate depth, which was the expected form. And the similar but insignificant trend was found in the other eight groups. One of the other groups showed the significant quadratic regression with the minimum catch at an intermediate depth, which was the type contrary to the expectation. The significant linear increase of the amount of catch per haul in accordance with the depth was found in the four groups of the records. The other nine groups of the records showed neither the significant quadratic regression nor the significant linear one.

The above-mentioned difficulty in finding out the depth depending change of the amount of catch per haul similar to that observable in the catch records of the traditional trawling may be due to either of the following two reasons: One is that the density of the objective fish did not show a well defined bathymetric difference; in other words, the depth fished was not one of the factors having a decisive influence on the density of the objective fish. The other is that the pattern found here is one of the characteristics of the catch pattern of the modern trawling; in other words, the change in the work pattern made it difficult to find the bathymetric change of the density of the objective fish through the records on the amount of catch by a haul because of the selective towing or the adjustment of the length of towing time. And whether the above-mentioned results were due to the former reason or due to the latter one may be found through the examination on the depth depending change of the number of hauls conducted in respective depth zones and that of the length of towing time.

### 3. The bathymetric change of the number of hauls

If the above-mentioned difficulty in finding out the depth depending change of the amount of catch per haul was due to the selective towing or the adjustment of the length of towing time, the bathymetric change of the density of the objective fish may be found in that of the number of the schools of the presumably profitable size found in respective depth zones, i.e. the number of hauls conducted. Or, if it was due to the latter reason, the bathymetric difference of the density may be found in that of the length of towing time. To find that the present case was either of the above-mentioned possibilities, the bathymetric change of the number of hauls was examined through the same method as in the examination on that of the amount of catch per haul. The results shown in Table 4 revealed the following facts: The number of hauls in all the 16 month-ground groups of the records showed such a trend that the boat conducted the most frequent hauls in an

Table 4. The regression equations of the number of hauls conducted in the zones of 25-m intervals ( $y$ ) on the depth fished ( $x$ in meters ) and the results of their significance test.

| Month | $a_0$ | $a_1$ | $a_2$ | $F_{2\cdot 1}$ | $F_{2\cdot 2}$ | $n$ |
|---|---|---|---|---|---|---|
| Dec. '68 | − 45.9 | 0.657 | −0.00194 | 3.78 | 4.11 | 7 |
| Jan. '69 | − 39.4 | 0.745 | −0.00198 | 0.85 | 1.10 | 10 |
| Feb. | − 86.4 | 0.815 | −0.00149 | 6.10* | 5.19 | 11 |
| March | −561.6 | 3.423 | −0.00484 | 16.41** | 16.18** | 9 |
| April | −173.7 | 1.038 | −0.00143 | 2.15 | 2.01 | 9 |
| May | − 39.1 | 0.440 | −0.00091 | 5.24* | 5.22* | 12 |
| July | −193.0 | 1.615 | −0.00282 | 9.72* | 10.83* | 11 |
| Aug. | −154.4 | 1.536 | −0.00304 | 30.45** | 30.32** | 11 |
| Sept. | −146.0 | 1.388 | −0.00260 | 18.01** | 17.83** | 12 |
| Oct. | −313.0 | 2.465 | −0.00428 | 13.42* | 12.38* | 9 |
| Nov. | − 68.4 | 0.771 | −0.00163 | 11.66** | 10.83* | 11 |
| Dec. | − 47.1 | 0.568 | −0.00151 | 16.86* | 17.02* | 6 |
| Jan. '70 | − 5.3 | 0.282 | −0.00076 | 0.73 | 1.22 | 12 |
| Feb. | − 28.6 | 0.311 | −0.00053 | 7.70* | 8.22* | 17 |
| March | −233.2 | 1.572 | −0.00231 | 14.54** | 14.51** | 12 |
| April | − 21.0 | 0.350 | −0.00072 | 2.77 | 3.29 | 14 |

Note: All the symbols are defined in Table 3. The equations for December of 1968 show the relations in the zones between 100 m and 250 m zones. Those for March of 1969 show the relations in the zones deeper than 275m. And those for May of 1969 show the relations in the Area A.

intermediate depth zone and less frequent hauls in accordance with the depth difference from this zone, although the quadratic regression coefficient of the number of hauls on the depth was not significant in the six groups. These facts meant that the change in the work pattern made the depth depending change of the density of the objective fish not observable in the records of the amount of catch per haul but observable in the records of the number of hauls.

### 4. The bathymetric change of the length of towing time

The results of the examinations in the preceding sections showed that the difficulty in finding out the bathymetric change of the distribution of the objective fish should be due to the selective attacking, and the bathymetric distribution of the fish was found in that of the number of hauls. But there remains the following possibility: The above-mentioned difficulty may be due to the adjustment of the length of towing time and the bathymetric difference of the density may be found in that of the length of towing time.

As shown in Table 5, the type of the depth depending change of the length of towing time varied according to the month-ground groups. The significant quadratic regression with the minimum length at an intermediate depth was found in the two month-ground

Table 5. The regression equations of the length of towing time ( $y$ in minutes ) on the depth fished ( $x$ in meters ) and the results of their significance test.

| Month | $a_0$ | $a_1$ | $a_2$ | $F_{2\cdot1}$ | $F_{2\cdot2}$ | $b_0$ | $b_1$ | $F_{1\cdot1}$ | $n$ |
|---|---|---|---|---|---|---|---|---|---|
| Dec. '68 | 18 | 1.21 | 0.0308 | 0.03 | 0.04 | 4 | 2.59 | 11.19** | 36 |
| Jan. '69 | 147 | − 7.90 | 0.1460 | 3.00 | 1.80 | 88 | −1.80 | 17.55** | 195 |
| Feb. | 247 | −14.92 | 0.2816 | 12.53** | 12.74** | 56 | 0.02 | 0.00 | 164 |
| March | 156 | − 5.52 | 0.0772 | 0.53 | 0.50 | 64 | −0.15 | 0.07 | 212 |
| April (A) | 692 | −37.22 | 0.5346 | 8.44** | 8.32** | 67 | −0.32 | 0.21 | 78 |
| May (A) | − 20 | 7.00 | −0.1067 | 2.82 | 1.54 | 40 | 1.89 | 9.67** | 86 |
| July | 257 | −12.23 | 0.2256 | 2.86 | 3.01 | 87 | 0.26 | 0.16 | 219 |
| Aug. | −134 | 17.25 | −0.3182 | 18.18** | 16.69** | 73 | 0.80 | 3.97* | 230 |
| Sept. | 118 | − 2.16 | 0.0399 | 0.28 | 0.28 | 89 | 0.00 | 0.00 | 235 |
| Oct. | 2 | 5.92 | −0.0903 | 1.17 | 0.91 | 76 | 0.73 | 3.71 | 209 |
| Nov. | 32 | 4.62 | −0.0659 | 1.74 | 0.76 | 65 | 1.60 | 13.47** | 135 |
| Jan. '70 | 152 | − 5.63 | 0.1290 | 2.94 | 2.85 | 98 | −0.13 | 0.10 | 158 |
| Feb. | 31 | 5.31 | −0.0880 | 10.47** | 10.92** | 107 | −0.02 | 0.00 | 161 |
| March | 178 | − 6.71 | 0.1107 | 1.13 | 1.47 | 48 | 0.91 | 2.71 | 202 |
| April | 118 | − 1.21 | 0.0099 | 0.31 | 0.05 | 113 | −0.73 | 7.26** | 200 |

Note: All the symbols are defined in Table 3.

groups of the records out of the 15 ones examined. The significant quadratic one showing the trend contrary to this was in the two groups; and the significant linear decrease was in the two groups and the significant linear increase was in the three groups; but the length of towing time in the six groups of the rest showed neither the significant quadratic regression nor the significant linear one.

The variability of the relation between the length of towing time and the depth may be either due to the unadequate adjustment of the length of towing time or due to the presence of some other factors having far stronger influence on the length of towing time than that of the depth or than that of the factor showing depth depending change. Whether the results were due to the former reason or not was examined in the succeeding sections.

### 5. The relation between the length of towing time and the amount of catch per haul

These differences of the results according to the factor chosen made the interpretation complicated. And the above-mentioned step of the examination was not sufficient to find whether the length of towing time was adequately adjusted according to the density of the objective fish or not. If the length of towing time is adequately adjusted, the boat yields the same amount of catch regardless of the length of towing time; namely, the amount of catch by a haul does not show any significant regression on the length of towing time. To clarify this point, the regressive relation of the amount of catch per haul on the length of towing time was examined.

As shown in Table 6, the significant quadratic regression was not found in all the groups of the records. The significant trend of decrease of the catch in accordance

Table 6. The regression equations of the amount of catch per haul ( $y$ in tons ) on the length of towing time ( $x$ in minutes ) and the results of their significance test.

| Month | $a_0$ | $a_1$ | $a_2$ | $F_{2\cdot1}$ | $F_{2\cdot2}$ | $b_0$ | $b_1$ | $F_{1\cdot1}$ | $n$ |
|---|---|---|---|---|---|---|---|---|---|
| Dec. '68 | 37 | −0.43 | 0.0019 | 1.38 | 0.44 | 31 | −0.19 | 5.04* | 36 |
| Jan. '69 | 37 | −0.38 | 0.0016 | 10.53** | 2.97 | 33 | −0.19 | 47.34** | 195 |
| Feb. | 30 | −0.13 | 0.0001 | 1.46 | 0.03 | 30 | −0.11 | 16.36** | 164 |
| March | 32 | −0.11 | 0.0007 | 3.00 | 2.18 | 30 | −0.02 | 1.17 | 212 |
| April (A) | 27 | 0.02 | −0.0003 | 0.01 | 0.03 | 27 | −0.01 | 0.09 | 78 |
| April (B) | 16 | 0.15 | −0.0009 | 0.50 | 0.43 | 20 | 0.01 | 0.12 | 116 |
| May (B) | 31 | −0.08 | −0.0001 | 0.01 | 0.00 | 32 | −0.09 | 1.08 | 53 |
| May (A) | 25 | 0.03 | −0.0005 | 0.01 | 0.08 | 28 | −0.07 | 1.85 | 86 |
| June (C) | 23 | −0.59 | 0.0063 | 1.26 | 2.59 | − 3 | 0.25 | 9.04** | 27 |
| July | 36 | −0.19 | 0.0008 | 4.02* | 2.70 | 30 | −0.04 | 3.54 | 219 |
| Aug. | 27 | −0.04 | −0.0000 | 0.06 | 0.00 | 27 | −0.04 | 2.80 | 230 |
| Sept. | 24 | 0.06 | −0.0007 | 0.13 | 0.48 | 28 | −0.05 | 3.03 | 235 |
| Oct. | 10 | 0.20 | −0.0009 | 0.94 | 0.67 | 18 | 0.03 | 1.06 | 209 |
| Nov. | − 1 | 0.35 | −0.0013 | 2.09 | 1.13 | 11 | 0.10 | 5.55* | 135 |
| Dec. | − 7 | 0.59 | −0.0035 | 0.33 | 0.39 | 19 | −0.04 | 0.15 | 20 |
| Jan. '70 | 42 | −0.41 | 0.0018 | 5.11* | 3.06 | 30 | −0.10 | 9.40** | 158 |
| Feb. | 23 | −0.00 | 0.0002 | 0.00 | 2.54 | 25 | 0.00 | 0.14 | 161 |
| March | 28 | 0.07 | −0.0004 | 0.34 | 0.38 | 31 | −0.00 | 0.01 | 202 |
| April | 46 | −0.38 | 0.0012 | 7.87** | 3.16 | 35 | −0.15 | 26.80** | 200 |

Note: All the symbols are defined in Table 3. The letter in parenthesis shows the abbreviation of the area defined in Fig. 1.

with the length of towing time was found in the five month-ground groups out of the 19 ones, although the same but the insignificant trend was found in the other nine groups. And the significant linear increase was found in the two other groups. These facts meant that, in most of the groups, the better catch was yielded by the shorter towing or the boat yielded the similar amount of catch regardless of the length of towing time. Namely, the length of towing time was adjusted according to the density of the fishable population, and the adjustment was either adequate or not sufficient to equalize the amount of catch by a haul, but it was rare that the towing time was over-adjusted.

The results of this section and the preceding ones meant that the length of towing time was adjusted but did not show any clear bathymetric change. And the examination on the bathymetric change of the number of hauls showed a possibility of the fish being distributed most abundantly on the sea floor of an intermediate depth. These results suggested such a possibility that the schools of sufficient size should be found most frequently on the sea floor of an intermediate depth but the difficulty in yielding a good catch should vary depending on some other factors than the depth, and the length

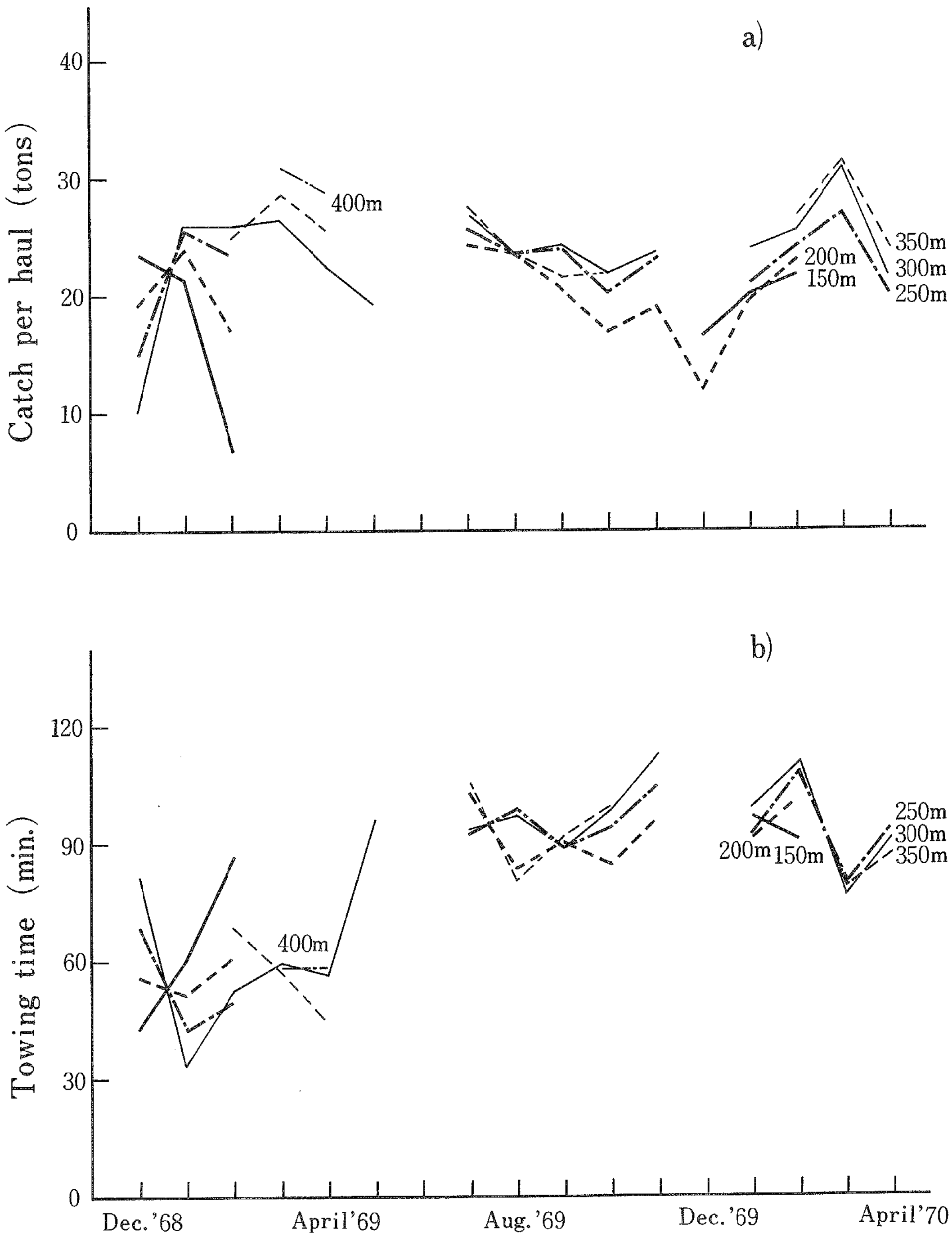


Fig. 3. The seasonal changes of the amount of catch per haul ( a ) and the length of towing time ( b ) in respective depth zones.

Note: For the months showing the insignificant quadratic regressions but the significant linear ones, the values estimated through the linear regression equations on the depth are shown in this figure; while the values for the other months are estimated through the quadratic regression equations.

of towing time should be adjusted according to this factor. The Alaska pollack is a roundfish capable of living not strictly depending on the sea floor. This fish may show daily rhythmic vertical movement pursuing the prey—planktonic crustaceans and small fish. But the trawl can catch only the fish living very closely to the sea floor. These facts suggested that the daily rhythmic vertical movement should be one of the most probable factors. The influence of this factor will be examined in the succeeding report.

### 6. The seasonal change of the bathymetric distribution of the amount of catch per haul

It was one of the principal aims of the present report to clarify the seasonal change of the catch pattern. As the material of the discussions in the succeeding sections, the seasonal change of the amount of catch per haul in respective depth zones was shown in Fig. 3, although many doubt is remaining in the meaning of the amount of catch per haul. This figure revealed the following facts: The amount of catch per haul in respective depth zones showed the similar trend to one another, except in the first month (Dec., '68), showing a slight increase in accordance with the depth fished. It was hard to find any clear trend capable of being regarded as the seasonal change, but it may be said that the amount of catch per haul was rather similar throughout the season examined.

### 7. The seasonal change of the bathymetric distribution of the number of hauls

The examinations in the preceding sections showed that, in the catch records of

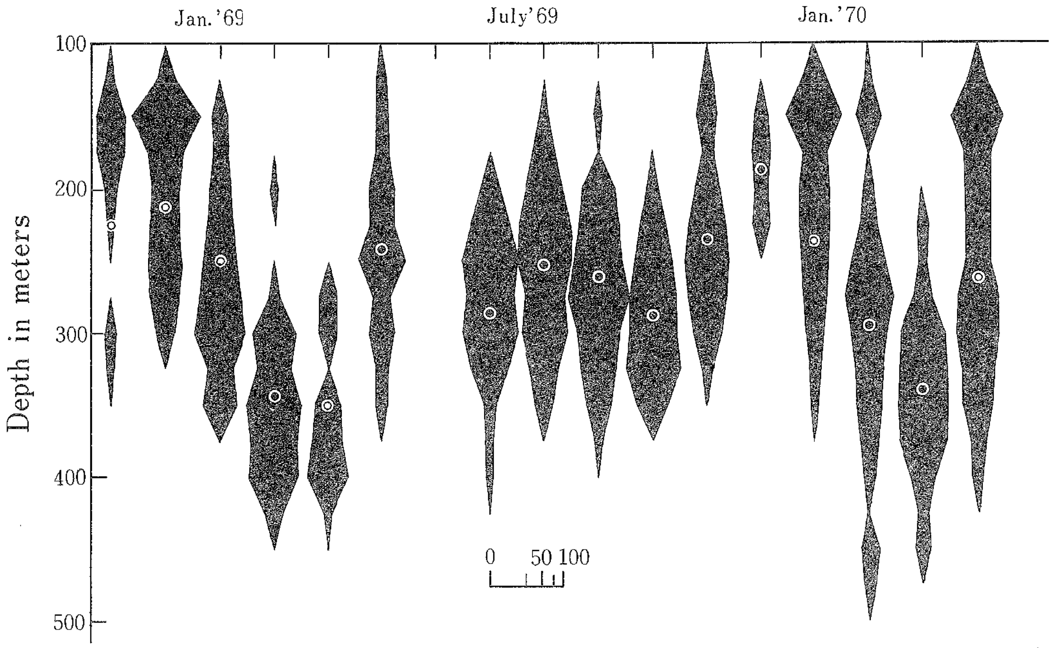


Fig. 4. The seasonal change of the bathymetric distribution of the number of hauls conducted in respective depth zones of 25-m intervals.

Note: The scale shows the number of hauls.
Solid circle ..... The depth showing the maximum number of hauls estimated through the significant quadratic regression equation
Open one ..... The average depth

the modern trawling, the number of hauls was the factor most clearly representing the bathymetric distribution of the objective fish because of the selective towing. The seasonal change of the bathymetric distribution of the hauls (Fig. 4) showed that the boat attacked the population in a little deeper ground during late winter and early spring than in the other season. But whether this fact was due to the seasonal change of the distribution of the objective fish or due to some reasons other than the biological ones was doubtful, because the distribution of the objective fish was not the exclusive factor making the boat shift her fishing ground. The boat had to shift her fishing ground according to the weather and the oceanographic conditions for the purpose of safety work. The influence of these factors is severe in the high latitudinal waters during winter and early spring; and the boat has to fish in the southern waters, i.e. in the deep grounds. The other finding from this figure was as follows: The significant quadratic regression was not found in the six month-ground groups of records. The bathymetric distribution of the hauls in these groups was either bimodal or showing a tailing. Most of these groups were in the transitional seasons either from the presumable migration towards the deep ground to that towards the shallow one or vice versa. And one of the modes or the tailing was in the similar depth to that in the preceding month and the other mode or the tailing was in the similar depth to that in the succeeding month.

### 8. The seasonal change of the bathymetric distribution of the length of towing time

The examination in the preceding section showed a trend capable of being regarded as the seasonal change of the bathymetric distribution of the objective fish, but the result was rather qualitative. The other factor applicable to represent the density of the fishable population was the relation between the amount of catch and the length of towing time. And, in the present case, the latter was applicable to the same purpose, because the former did not show any clear seasonal change. The other reason examining the seasonal change of the bathymetric distribution of the length of towing time was that the examination like this may make it possible to find out whether the length of towing time depends on the daily rhythmic change of the behavior of fish, because the length of daytime in the high latitudinal water shows a large seasonal change.

The monthly change of the length of towing time in respective depth zones was shown in Fig. 3b. The clearest trend found in this figure was not the trend capable of being regarded as the seasonal change but the small bathymetric difference and the abrupt elongation found between April and May or July of 1969. But further examinations were needed to find whether the elongation of towing time indicated the decrease of the density of the fishable population or not.

### 9. The seasonal change of the amount of catch by the hauls of the same length of towing time

The monthly change of the amount of catch by the hauls of the same length of towing time was shown in Fig. 5, for the purpose of examining whether the above-mentioned result meant the decrease of the density of the fishable population or not. This step of examination did not provide us with any fact suggesting the reason causing the trend found in the preceding section, but provided us with the trend capable of being regarded as the seasonal change of the density of the fishable population. Namely,

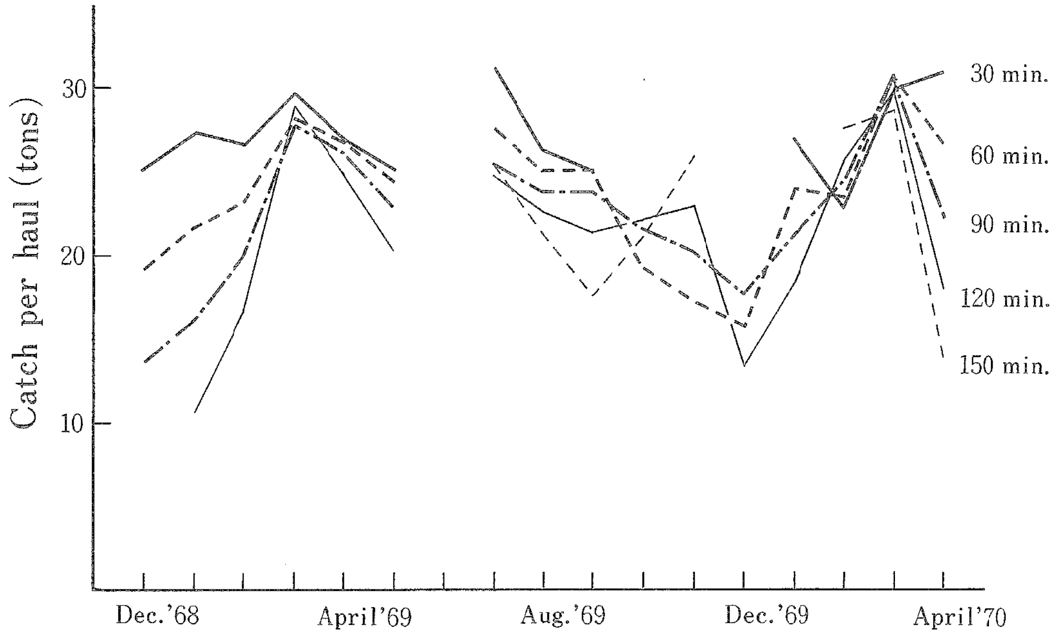


Fig. 5. The seasonal changes of the amount of catch yielded by the same length of towing time.

Note. The note is same as that in Fig. 3.

the clearest trend shown in this figure was the decrease of the catch per haul in late winter and early spring, although, as stated above, whether this trend was due to the seasonal change of the density of the fishable population or due to the southward shift of the position fished was doubtful.

## 10. The seasonal change of the frequency distribution of the hauls in respect of the length of towing time

The preceding steps of examinations found out that the monthly averages of the amount of catch per haul took rather similar values to one another throughout the season examined, but the towing time showed an abrupt elongation after May or July of 1969. These facts suggested the decreasing trend of the amount of catch by the hauls of the same length of towing time. But the result was different from the expectation. The fact responsible for causing the seeming contradiction of the result from the expectation could be found in the frequency distribution of the hauls in respect of the length of towing time. Namely, the composition of the hauls in respect of the length of towing time differed greatly in accordance with the passing of season. But it was not illustrated in Fig. 5.

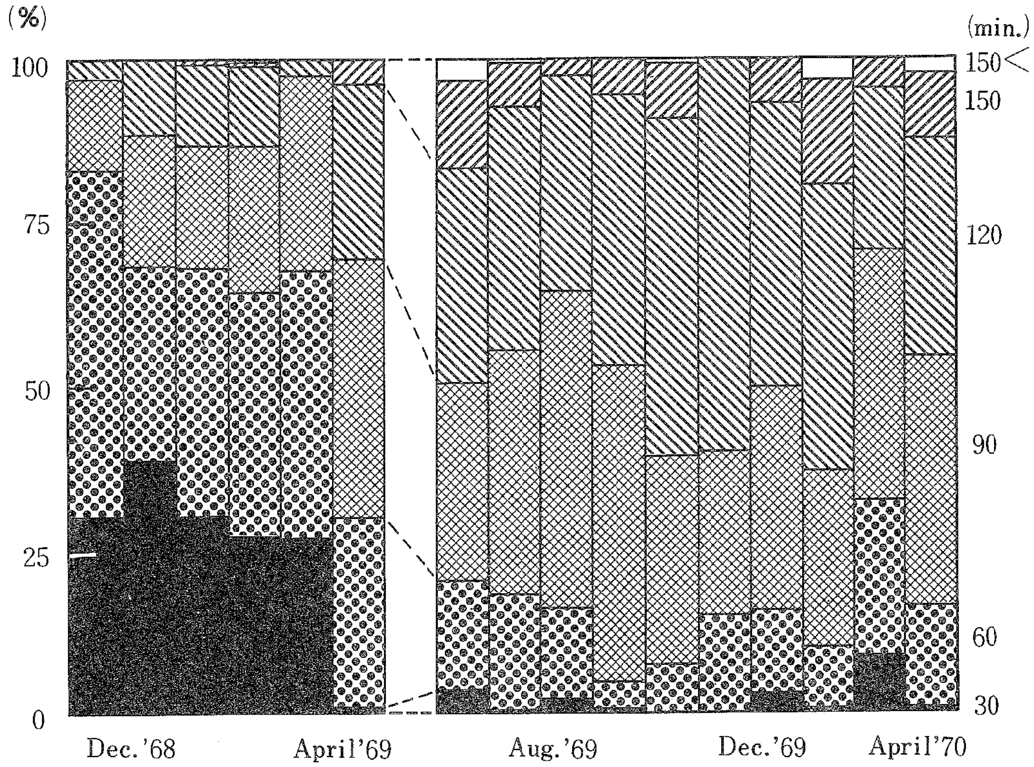


Fig. 6. The seasonal change of the composition of the hauls in respect of the length of towing time.

Note: The recorded value of the length of towing time was aggregated into the nearest 5-minute classes. Then, the frequencies of the hauls in the classes ( $x$ -25 ) to $x$ minutes were summed and illustrated as the class mark $x$ minutes.

In the earliest five months, i.e. just after the beginning of the exploitation of the Alaska pollack in the zone deeper than 150 m, the towing times of a little more than 25% of the hauls were within a half hour; those of about 75% of the hauls were within an hour; and those of about 85% of the hauls were not more than one and a half hour. An abrupt elongation of the towing time occurred between April and May or July of 1969; and the hauls with the towing of not more than a half hour fallen down into a negligibly small percentage; those with the towing of not more than an hour into less than 25%; and those with the towing of not more than one and a half hour into about 50%. These facts meant that a sudden change of the difficulty in finding out the concentration of the fish in very high density occurred between April and May or July of 1969. But the amounts of catch per haul of the towing of the same length in 1969–1970 took the similar values to those of the same months in 1968–1969 or rather increased. These facts suggested the following possibility: When the boat found the population of the same density, she yielded the similar amount of fish by the towing of the same length regardless of the years; but the difficulty in finding out the school of high density increased abruptly between April and May or July of 1969. And extensive studies were needed to clarify whether this fact was due to the objective fish being scattered by the fishing activities or this was the phenomenon observable commonly just after the invasion of the fishing into the unexploited population or this was due to some other reasons.

## Conclusion

The application of the echo-sounder and other electronic supporting devices brought the basic change in the details of the fishing techniques. And the trawler attacked selectively the presumably profitable schools and adjusted the length of towing time in accordance with the density of the fishable population or in accordance with the estimated amount of catch in the cod end during towing. These changes in the work pattern made the bathymetric difference of the density of the fishable population not observable in the records of the amount of catch per haul but observable in the records of the number of hauls conducted in respective depth zones. The trends capable of being regarded as the seasonal change were the shift of the boat into a little deeper ground and the decrease of catch yielded by the towing of the same length observable in late winter and early spring, although it was hard to find whether they were due to the seasonal change of the distribution of the objective fish or due to the southward shift of the fishing position caused by the other reasons than the biological ones.

One of the clearest trends found in the present report was the abrupt elongation of the towing time occurred between April and May or July of 1969. This was due to the increasing difficulty in finding out the concentration of fish in high density capable of supplying with sufficient catch with a short towing, although the amount of catch by the towing of the same length did not show the decreasing trend but took the similar value throughout the season or rather increased.

## Summary

The landing of the Alaska pollack showed a remarkable increase in the last decade. This was mainly brought by the two types of fisheries working in the Bering Sea. The changes of the amount of daily catch and the working speed of the Danish seiners in one of the types were examined in the preceding two series of reports. The other type was the stern ramp trawling fully supported by the newly developed electronic supporting devices. The introduction of these devices caused a basic change in the details of the fishing method of the trawling, consequently in the meaning of some of the items of the catch records. The present series of reports, accordingly, dealt with the

seasonal bathymetric change of the catch pattern and its relation to the working conditions observable in the catch records on the 3,132 hauls conducted during the first three trips of the large stern ramp factory trawler just after the inauguration of this type of fishery, for the purpose of showing the change in the catch pattern derived from the full application of electronic supporting devices. And the results obtained in the present report were summarized as follows:

1. The frequency distributions of the amount of catch in most of the groups of records of the hauls in the same depth zones (100 m intervals) of the same area during the same months were agreeable to the normal distribution. And it was hard to find any type of the theoretical distribution commonly agreeable to the observed series of the distribution in all or most of the groups of the rest.

2. The significant quadratic regression of the amount of catch per haul on the depth fished with a maximum catch at an intermediate depth zone, the expected form, was found only in the four of the month-ground groups out of the 18 ones examined.

3. In all the 16 month-ground groups, the boat conducted the most frequent hauls in an intermediate depth zone and less frequent hauls in accordance with the depth difference from this zone, although the quadratic regression coefficient was not significant in the six groups.

4. The other factor applicable to represent the bathymetric difference of the density of the fishable population was the length of towing time. But it was hard to find a general trend of its depth depending change.

5. In most of the month-ground groups, the similar amount of catch was yielded by a haul rather regardless of the length of towing time or better catch was yielded by the hauls of short towing.

6. It was hard to find a trend of the amount of catch per haul capable of being regarded as the seasonal change.

7. The boat attacked the population in a little deeper ground during late winter and early spring than in the other seasons.

8. The boat yielded poorer catch with the hauls of the same length of towing time in late winter and early spring than in the other seasons.

9. The abrupt elongation of the towing time occurred between April and May or July of 1969.

## References


1) MAÉDA, H. and S. MINAMI, 1965–1967: *Bull. Jap. Soc. Sci. Fish.*, **31**, 340–345; **32**, 511–516; **32**, 847–851; **33**, 176–180; **33**, 399–404.
2) MAÉDA, H. and S. MINAMI, 1969–1972: *Bull. Jap. Soc. Sci. Fish.*, **35**, 964–969; **35**, 970–974; **35**, 1043–1048; **36**, 455–461; **36**, 549–555; **36**, 1115–1121; **37**, 592–597; *This Jour.*, **20**, 1–12; **20**, 67–79; **20**, 135–156.
3) MINAMI, S. and H. MAÉDA, 1965–1967: *Bull. Jap. Soc. Sci. Fish.*, **31**, 346–349; **32**, 992–997; **33**, 731–737.
4) MINAMI, S., 1967: *Bull. Jap. Soc. Sci. Fish.*, **31**, 971–976.