An Analysis of the Catch Records of the Alaska Pollack Trawling – II.*

The Bathymetric Difference of the Amount of Catch by the Towings of the Same Time Length

By

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The minced product of the Alaska pollack is one of the most important protein resources for us exploited recently. And many large stern ramp factory trawlers equipped with the modern electronic supporting devices are engaging in its production. For the purpose of clarifying the state of the catch just after entering this type of fishery into a probably unexploited population, the seasonal change of the bathymetric distribution of catch was examined in the preceding report[1]. It was, however, hard to find the bathymetric difference of the density of the fishable population through the catch per towing of the modern trawler. This may be due to the selective attacking mainly for the directly detected dense schools and the adjustment of the length of towing time either according to the amount of catch in the net or according to the range of the profitable density. These changes in the catch pattern made it possible to find the bathymetric distribution of the fish through the number of towings, but the results were qualitative. The different relation between the amount of catch by a towing and the length of towing time according to the depth and the season and the different length of towing time prevented us from adopting the amount of catch per unit hour of towing as representing the bathymetric change of the density and its seasonal change. These facts needed the further examinations on the relations among the amount of catch, the depth, and the length of towing time. And the multiple linear regression of the amount of catch on the trawled depth and on the length of towing time observable in the records used in the preceding report was examined, for the purpose of finding out the general trend. The records were stratified according to the season and the depth, and the relation between the amount of catch and the length of towing time was examined. Then, the records were stratified according to the season and the length of towing time, and the bathymetric change of

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the amount of catch after elimination of the influence of different length of towing time was shown in the present report.

Material and Method

The same materials used in the preceding report were used in the present report. They were the catch records of one of the minced fish factory trawlers of about 4,000 gross tons fished along the outer edge of the continental shelf of the Eastern Bering Sea during the season of Dec. 23 in 1969 to May 2 in 1970. Among the records on the 3,132 towings, the other fish than the Alaska pollack occupied more than 10% of catch in the 342 towings, and the gear was seriously damaged in the 54 towings. The records on these towings were excluded from the examination. And the records on the 2,736 towings were stratified according to the month and the location of the fishing ground shown in Fig. 1 of the preceding report.

The amount of catch by a towing varied from 0 to 60 tons; and the echo-sounded depth just before shooting the gear varied from 25 to 500 m, mainly from 150 to 400 m. In the present report, the formers were aggregated into the classes of 10-ton intervals, and the latters were into the classes of 25-m intervals, because the accuracy of measurement and the distribution were taken into account. And the multiple linear regression equation, the quadratic and linear regression ones of the amount of catch either on the length of towing time after stratification of the records according to the depth or on the depth after stratification of the records according to the length of towing time, were estimated; and those in the same month-ground groups were compared with one another.

Results

1. The multiple linear regression of the amount of catch on the trawled depth and the length of towing time

The amount of catch depends mainly on the interaction of the two groups of factors. One is the biological one. The representatives are the density, the distribution, and the behavior pattern. The other is the technical one. The representatives are the gear construction and the towing technique. The density and the distribution differ according to the fishing ground and show the seasonal bathymetric change. And it was hard to choose the behavior pattern as one of the independent variables, because it was hard to represent it quantitatively. The boat used the gear of the same construction throughout the season studied here. It was also hard to use the factors of the towing technique as the independent variables because of the same reason, except the length of towing time. Accordingly, the records were stratified according to the location of the fishing ground and the month, as shown in the preceding report. And the multiple linear regression of the amount of catch by a towing on the trawled depth and the length of towing time was examined.

As shown in Table 1, the regression coefficient on the trawled depth inclined to take positive value and the significant one was found in the five months out of the 15 ones mainly in winter. And that on the length of towing time inclined to take negative value

Table 1. The multiple linear regression equations of the amount of catch (y in tons) on the depth fished (x_1 in meters) and the length of towing time (x_2 in minutes).

Month	a_0	a_1	a_2	F_1	F_2	n_2
Dec.'68	37.7	−0.053	−0.14	1.06	2.06	33
Jan.'69	32.1	0.003	−0.18	0.04	42.43**	192
Feb.	11.3	0.067	−0.11	14.56**	17.82**	161
March	14.1	0.045	−0.02	8.05**	1.10	209
April	3.9	0.063	−0.007	6.89*	0.03	75
May	31.0	−0.014	−0.06	0.21	1.29	83
July	23.4	0.023	−0.04	1.51	3.67	216
Aug.	26.2	0.005	−0.04	0.12	2.90	227
Sept.	25.2	0.012	−0.05	0.38	3.03	232
Oct.	11.7	0.023	0.03	1.65	0.73	206
Nov.	− 1.2	0.069	0.06	9.91**	1.86	132
Jan.'70	26.4	0.017	−0.10	1.20	9.23**	155
Feb.	13.4	0.025	0.04	5.10*	2.27	158
March	35.8	−0.016	0.000	0.78	0.00	199
April	36.3	−0.004	−0.15	0.13	26.43**	197

$y = a_0 + a_1 x + a_2 x_2$

Note: The boat fished both in the Area A and B in April and May of 1969. However, the records in the Area A were used in these equations.
F_i .... The Snedecor's F value of the regression coefficient on x_i, with 1 and n_2 degrees of freedom
$n_2 = n - 3$, where n is the size of samples
*significant at 0.05 level **significant at 0.01 level

and the significant one was found in the four months also mainly in winter. These facts meant that the catch in the winter months increased in accordance with the trawled depth and that by the towing of short time was better than that by long towing. However, there remains a doubt as to the catch in the summer months showed insignificant regression on these factors because any or some of the following four reasons: 1) narrow depth range and small difference of the length of towing time, 2) narrow variation of the amount of catch regardless of the depth and the length of towing time, 3) high order regression with the maximum or the minimum of catch at the intermediate depth or the intermediate length of towing time, and 4) loose dependence on these factors. For the purpose of finding out the fact, the records were examined through the methods shown in the following sections.

2. The regression of the amount of catch on the length of towing time

The records in respective month-ground groups were stratified into the depth sub-

Table 2. The estimated quadratic and linear regression equations of the amount of catch (y in tons) on the length of towing time (x in minutes) observable in the groups of the records stratified according to the month, the ground, and the trawled depth (into the nearest 25-m intervals).

Month	Depth (m)	a_0	a_1	a_2	$F_{2\cdot1}$	$F_{2\cdot2}$	b_0	b_1	$F_{1\cdot1}$	n
Dec. '68	150	49	−1.23	0.0111	2.83	2.47	25	−0.12	0.37	16
	175	18	0.37	−0.0046	0.13	0.24	30	−0.12	0.39	12
Jan. '69	150	35	−0.39	0.0017	5.60*	1.89	29	−0.17	19.37**	92
	175	47	−0.78	0.0043	10.34**	5.64*	34	−0.22	11.34**	24
	200	27	0.14	−0.0039	0.06	0.47	35	−0.25	3.76	14
	225	50	−1.01	0.0053	3.50	1.61	37	−0.35	5.68**	16
	250	11	0.43	−0.0038	3.29	4.27	21	−0.05	0.52	19
	275	12	0.90	−0.0093	2.46	3.44	31	−0.15	2.13	15
Feb.	225	36	−0.38	0.0011	1.23	0.19	33	−0.23	13.97**	13
	250	27	−0.20	0.0002	0.44	0.00	27	−0.18	4.53*	21
	275	27	0.20	−0.0033	0.61	2.51	34	−0.19	7.73**	30
	300	24	0.00	−0.0002	0.00	0.02	25	−0.03	0.33	49
	325	47	−0.64	0.0043	1.65	1.24	34	−0.09	1.22	11
	350	15	0.15	−0.0006	0.09	0.03	18	0.06	0.64	23
March	300	18	0.21	−0.0016	1.34	1.37	23	0.005	0.01	36
	325	34	−0.37	0.0026	5.29*	2.98	30	−0.11	3.21	23
	350	30	−0.01	−0.0002	0.01	0.04	31	−0.04	1.13	57
	375	27	0.01	0.0000	0.00	0.00	27	0.06	0.01	39
	400	36	−0.29	0.0019	10.37**	12.89**	27	0.01	0.13	47
April (A)	350	21	0.02	0.0005	0.00	0.03	20	0.09	0.93	12
	375	33	−0.52	0.0061	2.40	3.23	22	0.07	1.03	18
	400	36	−0.17	0.0005	0.27	0.02	35	−0.12	3.58	34
April (B)	100	17	0.01	−0.0002	0.00	0.01	18	−0.01	0.14	95
	125	158	−3.71	0.0250	3.62	3.97	14	0.17	1.88	21
May (B)	125	30	−0.07	−0.0003	0.01	0.00	31	−0.11	1.40	53
May (A)	200	−1	0.47	−0.0030	0.87	0.97	16	−0.02	0.04	13
	225	20	0.43	−0.0042	0.05	0.14	49	−0.29	2.10	10
	250	69	−0.94	0.0048	3.73	2.88	36	−0.12	2.88	37
	300	−167	3.64	−0.0179	1.15	1.20	21	−0.07	0.11	11
June (C)	50	14	−0.33	0.0041	0.34	0.88	−1	0.20	5.27*	25
July	225	42	−0.47	0.0025	2.51	2.83	20	0.02	0.13	26
	250	26	0.02	−0.0002	0.01	0.04	28	−0.02	0.26	52
	275	36	−0.22	0.0006	1.15	0.30	32	−0.11	6.67*	42
	300	32	−0.10	0.0003	0.27	0.07	30	−0.05	1.87	59
	325	31	−0.07	−0.0001	0.10	0.01	32	−0.09	2.42	27
Aug.	200	30	−0.02	−0.0006	0.00	0.05	35	−0.13	3.73	25
	225	−13	0.87	−0.0051	5.96*	6.19*	22	−0.00	0.00	50
	250	5	0.26	−0.0009	0.52	0.24	13	0.09	2.76	52
	275	25	−0.04	−0.0001	0.01	0.00	26	−0.06	1.18	33
	300	59	−0.59	0.0021	3.24	1.82	37	−0.15	8.15**	38
	325	6	0.68	−0.0052	0.89	1.47	39	−0.19	5.38*	16

Table 2 continued

Month	Depth (m)	a_0	a_1	a_2	$F_{2\cdot1}$	$F_{2\cdot2}$	b_0	b_1	$F_{1\cdot1}$	n
Sept.	200	− 19	0.99	−0.0059	0.70	0.73	21	−0.01	0.01	18
	225	− 35	1.34	−0.0077	5.05*	4.87*	18	0.04	0.16	32
	250	− 13	0.87	−0.0051	3.93	3.89	19	0.02	0.05	42
	275	37	−0.26	0.0011	0.72	0.39	29	−0.07	1.74	70
	300	8	0.36	−0.0023	0.32	0.39	24	−0.03	0.17	35
	325	32	−0.02	−0.0006	0.00	0.12	35	−0.12	3.50	24
	350	127	−2.12	0.0094	4.14	3.93	19	−0.07	0.28	12
Oct.	225	− 13	0.70	−0.0034	1.97	1.15	5	0.18	2.91	14
	250	− 36	0.94	−0.0039	2.09	1.23	− 4	0.23	4.64*	26
	275	− 49	1.32	−0.0063	4.56*	4.05	11	0.08	1.28	43
	300	9	0.23	−0.0012	0.43	0.40	19	0.01	0.03	44
	325	45	−0.50	0.0024	1.50	1.39	22	−0.02	0.17	59
	350	63	−0.90	0.0043	0.21	0.19	23	−0.06	0.15	21
Nov.	200	− 53	1.43	−0.0072	0.82	0.66	− 0.3	0.15	1.06	13
	225	62	−0.67	0.0025	5.41*	4.35*	30	−0.08	1.93	25
	250	− 6	0.44	−0.0018	0.73	0.51	11	0.08	0.85	37
	275	55	−0.64	0.0032	1.08	1.21	22	0.03	0.15	28
	300	57	−0.68	0.0028	0.35	0.22	33	−0.15	3.19	16
Jan.'70	125	11	0.38	−0.0024	0.07	0.08	28	−0.04	0.09	12
	150	27	−0.20	0.0009	0.34	0.25	20	−0.03	0.35	62
	175	48	−0.72	0.0034	1.79	1.20	28	−0.14	1.73	13
	200	32	−0.22	0.0005	0.42	0.05	30	−0.15	5.43*	17
	225	93	−1.56	0.0075	3.88	2.73	43	−0.26	8.72**	17
	250	38	−0.37	0.0018	0.12	0.08	24	−0.06	0.25	15
	275	43	−0.48	0.0023	0.26	0.23	22	−0.03	0.12	11
Feb.	150	− 6	0.66	−0.0044	0.44	0.64	27	−0.13	1.13	12
	250	13	0.35	−0.0019	1.20	1.33	28	−0.01	0.04	24
	275	78	−1.05	0.0048	8.90**	8.62**	28	−0.03	0.22	44
	300	58	−0.76	0.0037	8.26**	9.06**	20	0.02	0.07	25
	325	− 33	0.83	−0.0030	3.21	2.80	14	0.06	0.93	15
	350	− 12	0.82	−0.0046	0.89	0.83	19	0.04	0·09	12
March	300	− 24	0.12	−0.0004	0.23	0.04	25	0.07	1.99	37
	325	25	0.13	−0.0008	0.28	0.30	29	−0.001	0.001	45
	350	29	0.01	−0.0002	0.01	0.04	30	−0.02	0.27	48
	375	31	−0.08	0.0006	0.09	0.14	27	0.02	0.12	45
	400	− 40	1.71	−0.0106	4.16	4.38	25	−0.02	0.01	12
April	150	41	−0.29	0.0007	1.39	0.40	33	−0.14	8.31**	49
	175	93	−1.54	0.0070	10.06*	9.34*	24	−0.07	0.52	12
	200	49	−0.43	0.0015	0.43	0.14	41	−0.19	4.68	11
	225	3	0.42	−0.0022	0.06	0.03	12	0.12	0.38	10
	250	41	−0.35	0.0005	0.06	0.01	37	−0.25	4.26	10
	275	69	−1.15	0.0058	3.45	3.46	17	−0.01	0.01	27
	300	− 19	0.93	−0.0055	2.14	2.60	25	−0.09	1.00	36
	325	28	0.16	−0.0025	0.11	0.82	44	−0.27	10.98**	17
	350	17	0.43	−0.0039	0.62	1.27	37	−0.17	2.82	16

Note: $y = a_0 + a_1x + a_2x^2$ or $y = b_0 + b_1x$

F_{ij} ....The Snedecor's F value for the j-th order regression coefficient in the i-th order regression equation, with 1 and $(n - i - 1)$ degrees of freedom

n .... Size of samples

The letter in parenthesis is the abbreviation of the area shown in Fig. 1 of the preceding report. *significant at 0.05 level **significant at 0.01 level

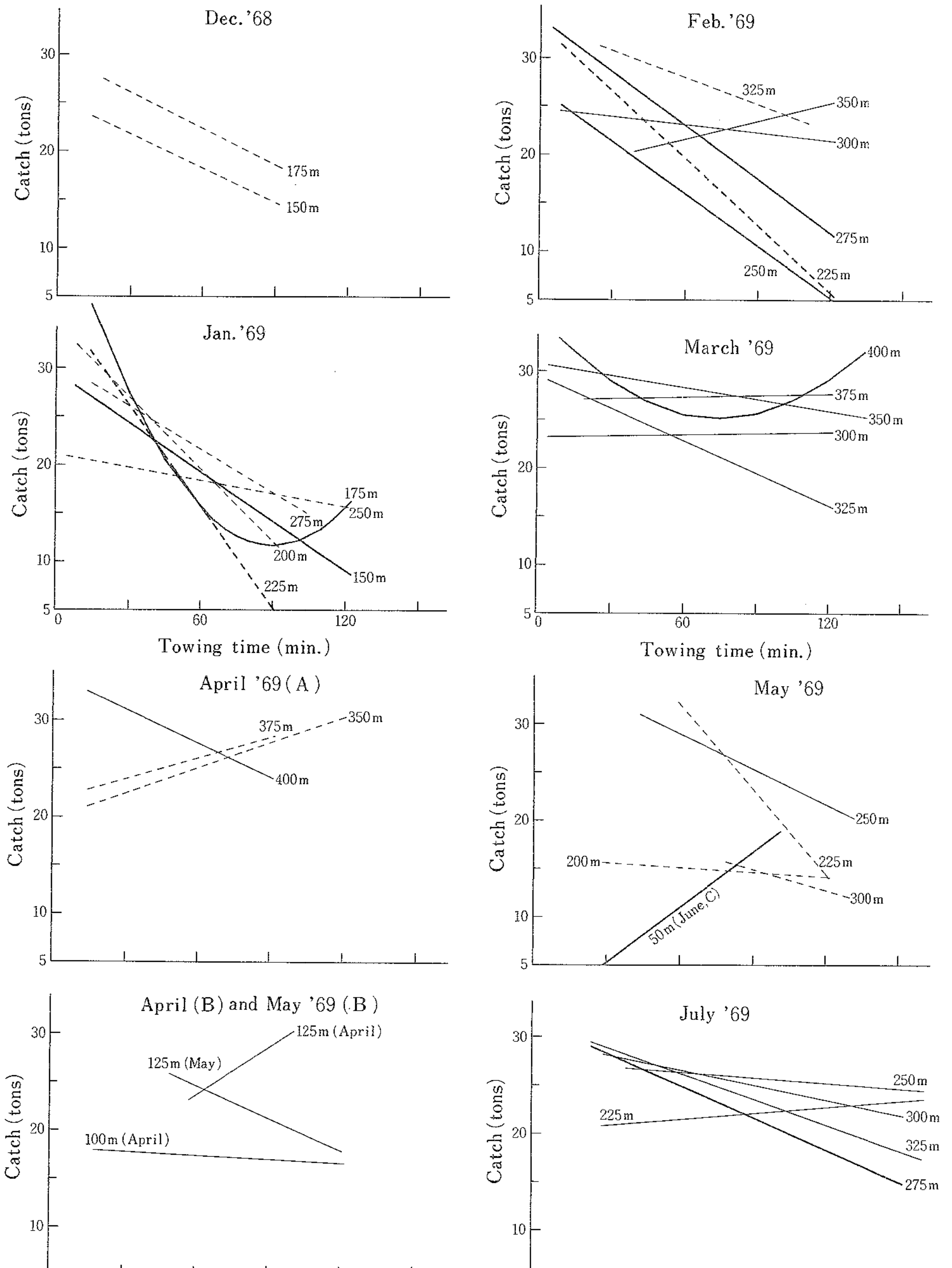
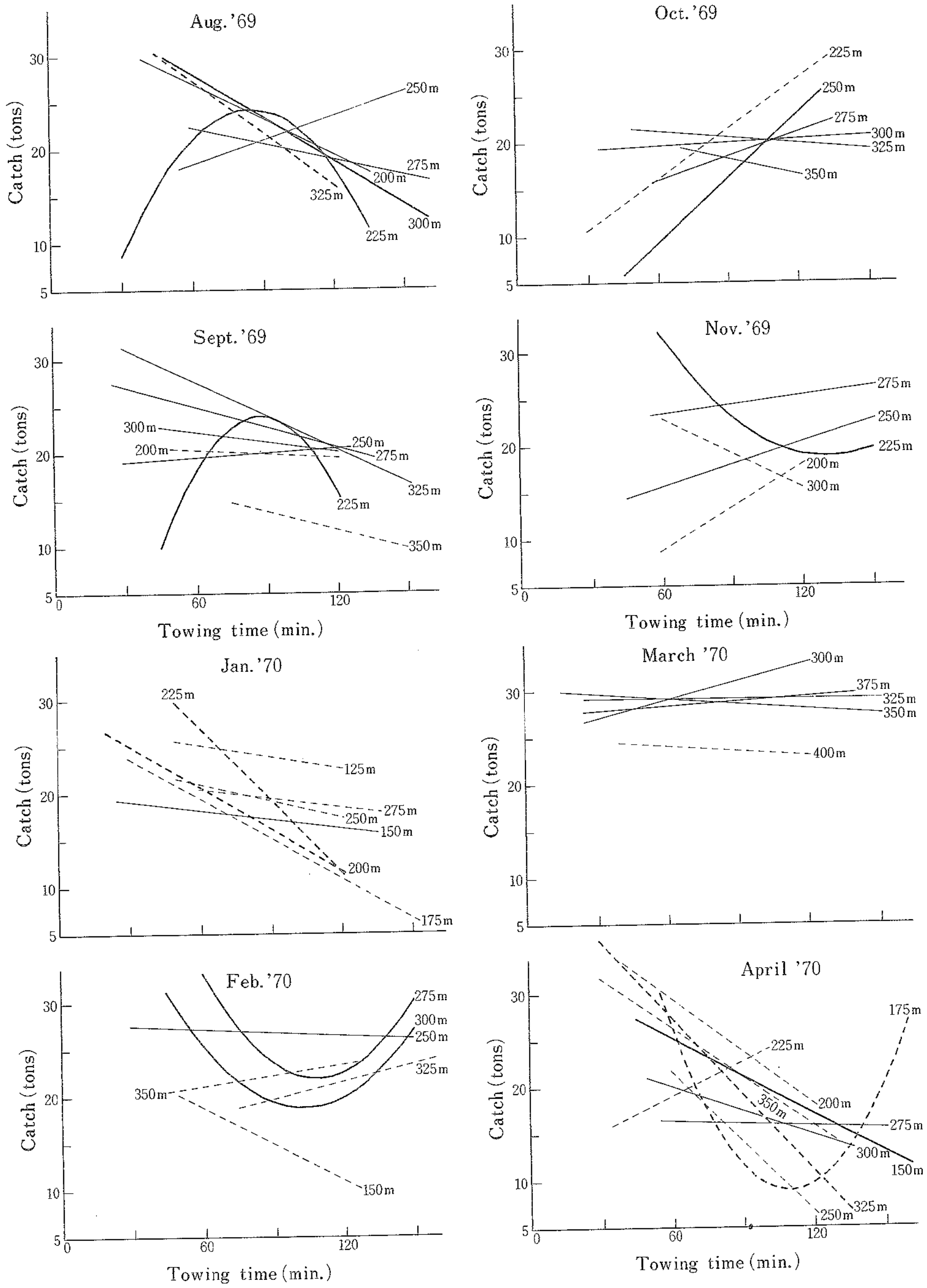


Fig. 1. The estimated regression lines of the amount of catch on the length of towing time.

Note: The equations are shown in Table 2. The numerals attached the line are the trawled depth in meters (25-m intervals).



Thick curve .... Significant quadratic regression
Thick line .... Significant linear one (insignificant quadratic one)
Thin line .... Insignificant linear one (insignificant quadratic one)
Solid line .... The relation in the stratum consisted of more than 20 records
Broken line .... That of the stratum consisted of 10 to 19 records

groups of the 25-m intervals. And the quadratic and linear regressions of the amount of catch on the length of towing time were examined.

As shown in Table 2, whether the coefficient was significant or not being left aside, the amount of catch by a towing showed the convex relation to the length of towing time in the 41 sub-groups of the records and the concave one in the 45 sub-groups out of the 86 sub-groups, and it was hard to find any clear relation between the distribution of these types and either the month or the depth. The former trend was significant in the two sub-groups in the summer months in the shallow zones, and the latter was significant in the six sub-groups mainly in the winter months in the extreme depth zones. Among the 78 sub-groups showing insignificant quadratic regression, the decreasing trend was found in the two-thirds of them and the increasing one was in the one-third, and it was hard to find any clear relation between their distribution and either the depth or the season. The former trend was significant in the 12 sub-groups, and the latter was significant in the two of them. And it was hard to find any clear relation between their distribution and either the depth or the season. Namely, the amount of catch in the 64 sub-groups out of the 86 ones showed neither any significant quadratic regression nor any significant linear one on the length of towing time. And the similar amount of catch was yielded by a towing regardless of its time length in the three-fourths of the sub-groups, in spite of the large variation of the length of towing time.

The estimated regression equations were classified into the three types according as the regression coefficient was 1) large negative, 2) small (including both the positive value and the negative one), and 3) large positive. And a few of the depth zones showing the different trend was excluded, and the equations of the same months were compared with one another. Then, the following trends were found out:

1. Small coefficient in all the depth zones
   March and April (A) in 1969, and March in 1970
2. Large negative coefficient in all the depth zones
   January, (July), and August in 1969, and April in 1970
3. Separation of the depth zones in respect of the catch-time relation
   - 3.1. Small coefficient in deep zones and large negative one in shallow zones
     February in 1969
   - 3.2. Small coefficient in deep zones and large positive one in shallow zones
     October in 1969
   - 3.3. Small coefficient in the extreme depth zones and large negative one in intermediate depth zones
     May in 1969 and January in 1970
   - 3.4. The coefficient decreases roughly with depth
     September in 1969
4. Showing large and irregular variation of the coefficient according to the depth zone
   Clearly in November in 1969 Not clearly in February in 1970

Namely, in the seven months, all the depth zones showed the same trend. Among them, the coefficient of all the lines in the three months (March and April in 1969, and March in 1970) was small (in these months, the boat trawled only in the deep zones—deeper than 300 m). And the coefficient of all the lines in the four months [January, (July), and August in 1969 and April in 1970] took negative value. In the other months, the small coefficient was found mainly in the deeper zones (February, May, and October in 1969, and January in 1970) or partly in the shallower extreme too (May in 1969 and January in 1970). The large negative coefficient was in the shallower half (February in 1969) or in the intermediate depth zones (May in 1969 and January in 1970). And the large positive coefficient was found only in the months showing irregular variations of the coefficient and the catch not relating to the depth (November in 1969 and February in 1970), except October in 1969 (mainly in the shallower half).

The fishing depth showed a seasonal difference, and its variation showed a large monthly difference. These facts were taken into account. Then, the following rough trend was found out: The large negative coefficient was found mainly in the zones shallower than 300 m and the small one was in the zones deeper than this depth.

3. The regression of the amount of catch on the depth observable among the records of the towings on the same months by the towings of the same time lengths

The amount of catch per minute or per hour of towing was used in many of the reports for the comparison of the density of the fishable population, eliminating the influence of the different time length of towings. This is effective to represent the density variation. However, the preceding section showed that the relation between the amount of catch and the length of towing time was complicated. And this was not suitable for the discussion, when the different work pattern of the modern trawlers was taken into account. In the present case, the records of the same month-ground groups were stratified according to the length of towing time (5-minute intervals). And the quadratic and linear regressions of the amount of catch on the trawled depth were examined.

As shown in Table 3, whether the coefficient was significant or not being left aside, the amount of catch by a towing showed the convex relation to the depth in the 53 sub-groups of the records, and the concave one in the 31 sub-groups out of the 84 sub-groups. And it was hard to find any clear relation between their distribution and either the season or the length of towing time, except the trend that the catch-depth relation from April to August inclined to be convex. And attention was paid to the fact that the meaning of the towing of the same time length differed according to the season: For example, the towing of 60 minutes was longer one on January in 1969, while it was shorter one after July of the same year, because the towing time showed an elongation with passing of season. This fact was taken into account, but it was also hard to find any clear relation between their distribution and either the season or the length of towing time. The convex relation was significant in the three sub-groups and the concave one was significant in the two sub-groups. They were scattering over the different months and different time classes. Among the 79 sub-groups of the records showing insignificant

Table 3. The estimated quadratic and linear regression equations of the amount of catch (y in tons) on the trawled depth (x in meters) observable in the groups of records stratified according to the month, the ground, and the length of towing time (5-minute intervals)

Month	Towing time (min.)	a_0	a_1	a_2	$F_{2\cdot1}$	$F_{2\cdot2}$	b_0	b_1	$F_{1\cdot1}$	n
Jan.'69	15	11	0.20	−0.0005	0.08	0.10	32	−0.01	0.05	17
	20	119	−0.88	0.0021	1.06	1.12	26	0.02	0.11	16
	25	−111	1.42	−0.0034	5.04*	5.32*	36	−0.03	0.32	13
	30	147	−1.25	0.0030	4.90*	5.01*	21	0.01	0.02	24
	40	56	−0.26	0.0004	0.21	0.10	38	−0.08	2.52	15
	50	−236	3.05	−0.0089	3.99	4.32	36	−0.11	0.64	11
	60	−53	0.68	−0.0015	1.31	1.23	12	0.02	0.15	23
	90	112	−1.01	0.0024	1.43	1.25	26	−0.07	0.80	17
	120	12	0.09	−0.0005	0.02	0.09	30	−0.10	4.61	10
Feb.	15	−223	2.03	−0.0041	0.83	0.90	47	−0.08	0.30	11
	25	97	−0.57	0.0011	0.41	0.43	25	0.01	0.02	10
	30	−340	2.89	−0.0056	3.74	3.56	0.3	0.08	0.49	11
	40	110	−0.37	0.0003	0.06	0.01	83	−0.19	6.17*	14
	60	−28	0.26	−0.0003	0.55	0.24	−7	0.09	6.08*	25
	80	−190	1.33	−0.0021	0.50	0.41	−18	0.13	1.35	10
	90	−346	2.32	−0.0036	0.49	0.46	1	0.07	0.33	10
	120	65	−0.56	0.0013	19.15**	27.23**	−14	0.10	10.78*	10
March	15	−633	3.62	−0.0049	4.54	4.20	−22	0.15	1.72	10
	20	96	−0.45	0.0007	0.19	0.26	2	0.07	1.97	14
	30	−184	1.29	−0.0019	1.43	1.55	48	−0.05	1.00	14
	40	15	−0.05	0.0002	0.002	0.02	−15	0.12	3.61	17
	50	−107	0.75	−0.0010	0.54	0.50	16	0.03	0.62	13
	60	−199	1.38	−0.0021	2.27	2.50	47	−0.07	2.14	34
	80	270	−1.37	0.0019	1.20	1.26	15	0.03	0.18	13
	90	−364	2.14	−0.0029	2.27	2.06	−9	0.10	1.68	17
	120	443	−2.47	0.0036	1.55	1.63	6	0.06	0.25	10
April	60	3	0.69	0.0005	0.24	0.29	14	0.03	1.88	16
May	60	−67	0.82	−0.0018	8.88*	8.91*	19	0.01	0.04	14
	90	−111	1.04	−0.0020	0.31	0.25	−7	0.11	1.35	20
	120	−145	1.31	−0.0026	3.37	3.56	22	−0.03	0.50	15
July	60	−118	1.07	−0.0020	1.31	1.28	16	0.02	0.05	11
	70	−121	1.10	−0.0021	1.06	0.98	10	0.04	0.24	13
	80	−5	0.23	−0.0005	0.01	0.01	29	−0.02	0.05	14
	90	−73	0.74	−0.0014	0.77	0.76	24	0.005	0.01	22
	95	624	−4.51	0.0084	3.59	3.63	19	0.02	0.03	12
	100	−0.2	0.10	−0.0001	0.02	0.001	3	0.08	2.97	15
	120	−160	1.36	−0.0025	1.82	1.88	26	−0.02	0.13	26
Aug.	60	145	−1.02	0.0020	3.84	4.18	11	0.04	0.72	24
	65	4	0.10	−0.0001	0.002	0.001	11	0.05	0.20	11
	75	−25	0.41	−0.0008	0.12	0.13	30	−0.01	0.05	10
	80	−72	0.66	−0.0012	0.14	0.12	4	0.06	0.63	13
	90	−30	0.39	−0.0007	0.90	0.88	19	0.01	0.03	36
	105	−13	0.28	−0.0005	0.13	0.11	17	0.02	0.10	14
	110	−83	0.85	−0.0017	1.10	1.29	41	−0.07	1.59	19
	120	−46	0.48	−0.0009	0.39	0.38	16	0.01	0.02	32

Table 3 continued

Month	Towing time (min.)	a_0	a_1	a_2	$F_{2\cdot1}$	$F_{2\cdot2}$	b_0	b_1	$F_{1\cdot1}$	n
Sept.	50	211	−1.76	0.0039	4.06	5.11	−34	0.21	5.62*	10
	75	79	−0.45	0.0009	0.26	0.33	11	0.06	0.90	17
	80	−310	2.41	−0.0043	2.47	2.76	60	−0.13	1.64	15
	85	34	0.01	−0.0002	0.0002	0.01	46	−0.08	1.05	14
	90	− 67	0.64	−0.0012	4.11*	3.80	13	0.03	0.65	54
	100	197	−1.16	0.0019	1.00	0.94	32	−0.04	0.18	11
	105	70	−0.33	0.0005	0.15	0.11	31	−0.05	0.43	13
	110	31	0.06	−0.0003	0.004	0.04	57	−0.12	2.45	12
	120	−169	1.40	−0.0026	8.89**	8.79**	14	0.01	0.08	34
Oct.	75	− 9	−0.01	0.0003	0.0001	0.03	−34	0.17	8.29*	11
	80	−108	0.98	−0.0019	0.27	0.33	48	−0.10	1.72	16
	90	54	−0.20	0.0003	0.16	0.10	32	−0.04	1.32	56
	100	− 17	0.22	−0.0003	0.13	0.06	4	0.07	2.07	20
	105	− 38	0.30	−0.0004	0.49	0.26	− 9	0.08	7.58*	12
	110	−101	0.91	−0.0017	0.88	0.99	34	−0.05	0.48	12
	120	78	−0.35	0.0005	0.09	0.06	34	−0.05	0.68	30
Nov.	90	− 87	0.91	−0.0019	3.85	3.11	− 5	0.10	2.87	25
	120	− 51	0.57	−0.0011	2.24	2.13	16	0.02	0.18	39
Jan.'70	80	39	−0.34	0.0010	0.30	0.54	− 6	0.11	3.75	11
	90	48	−0.21	0.0003	0.75	0.40	33	−0.06	3.29	24
	120	73	−0.58	0.0015	3.17	3.25	17	0.004	0.02	37
Feb.	90	4	0.10	−0.0001	0.44	0.24	14	0.03	1.14	24
	120	− 6	0.18	−0.0003	2.65	2.36	18	0.01	0.38	41
March	25	252	−1.45	0.0023	0.48	0.51	19	0.03	0.15	10
	45	766	−4.35	0.0064	0.99	0.95	62	−0.10	1.11	11
	60	− 80	0.55	−0.0007	0.96	0.91	19	0.02	0.13	13
	65	38	−0.03	0.00001	0.005	0.0002	37	−0.03	0.40	10
	70	−656	4.15	−0.0062	4.03	3.89	5	0.08	0.49	14
	80	265	−1.33	0.0019	0.38	0.37	35	−0.01	0.03	16
	85	−191	1.34	−0.0020	1.75	1.95	52	−0.07	1.18	11
	90	− 68	0.57	−0.0008	0.91	1.09	48	−0.05	0.96	21
	120	−103	0.84	−0.0013	2.00	2.00	25	0.004	0.006	23
April	60	6	0.002	0.0002	0.0000	0.07	− 7	0.10	4.92	10
	70	− 11	0.39	−0.0009	0.80	1.06	36	−0.06	2.30	11
	75	101	−0.79	0.0017	1.64	1.63	18	−0.004	0.005	11
	80	27	−0.15	0.0004	0.15	0.33	2	0.07	3.61	10
	90	55	−0.32	0.0007	1.41	1.36	21	−0.01	0.08	32
	100	62	−0.30	0.0005	0.70	0.44	37	−0.06	3.56	13
	120	− 4	0.13	−0.0002	0.23	0.16	7	0.02	0.82	33

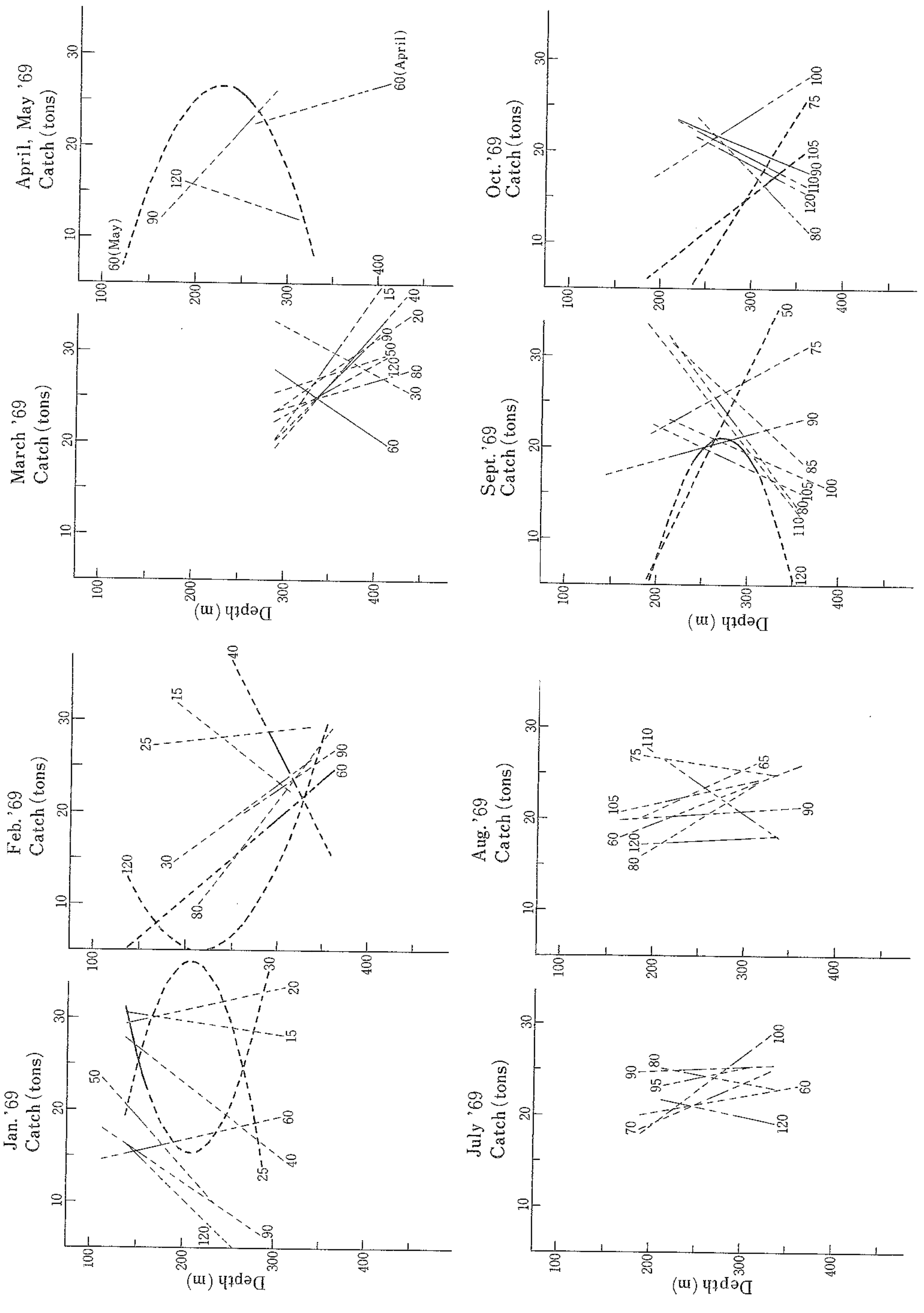
Note: $y = a_0 + a_1x + a_2x^2$ or $y = b_0 + b_1x$

F_{ij} .... The Snedecor's F value for the j-th order regression coefficient in the i-th order regression equation, with 1 and $(n - i - 1)$ degrees of freedom

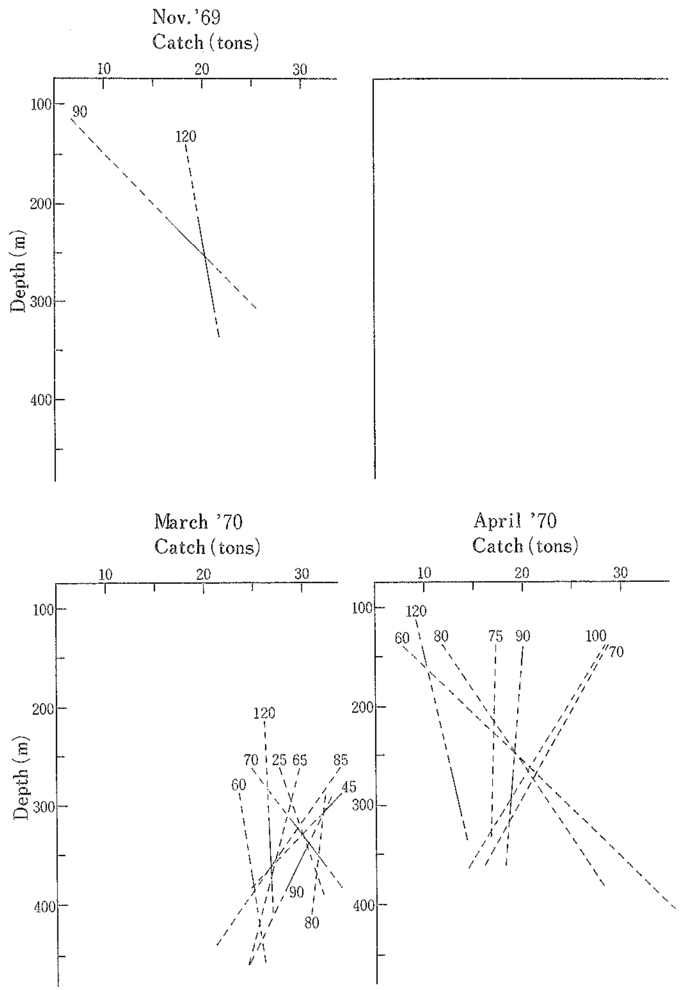
n ..... Size of samples

The records in the Area B and C are omitted, because they are distributed within narrow depth zones.

*significant at 0.05 level **significant at 0.01 level



April, May '69
Catch (tons)
Oct. '69
Catch (tons)
March '69
Catch (tons)
Sept. '69
Catch (tons)
Feb. '69
Catch (tons)
Aug. '69
Catch (tons)
Jan. '69
Catch (tons)
July '69
Catch (tons)
Depth (m)



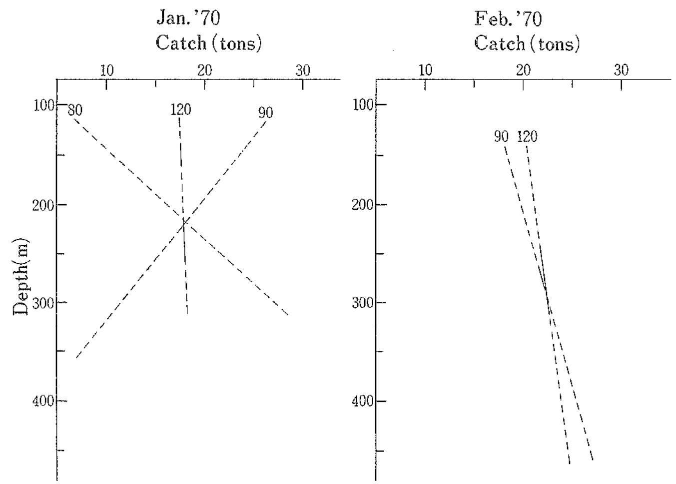


Fig. 2. The estimated regression lines of the amount of catch on the trawled depth.

Note: The equations are shown in Table 3. The numerals attached the line are the length of towing time (5-minute intervals).
Thick curve........Significant quadratic regression
Thick line...........Significant linear one (insignificant quadratic one)
Thin line............Insignificant linear one (insignificant quadratic one)
The part of solid line........The depth zones of more than 5 records
The part of broken one......Applicable range, but the records being less than five per 25m.

quadratic regression, the increasing trend was found in the 46 sub-groups and the decreasing one was in the 33 sub-groups. It was hard to find any clear relation between their distribution and either the season or the length of towing time, even when the different meaning of the towings of the same time length according to the season was taken into account. The former trend was significant in the five sub-groups and the latter was significant in the one sub-group. They were scattering over the different months and in the different time classes. Namely, the amount of catch in 87% of the sub-groups did not show any significant regression on the depth.

For the purpose of assisting easy understanding of the relation between the bathymetric change of the catch and the length of towing time, the regression equations were illustrated in Fig. 2. This figure revealed the following trends:

1. Decrease of catch with depth, similar amount of catch regardless of the length of towing time
   March in 1969
2. Decrease of catch with depth, sharp decrease of it with towing time
   January in 1969
3. Decrease of catch with depth by short towings, and increase of it with depth by long towings
   3.1. Decrease with towing time in the shallow zones and the similar amount of catch regardless of the towing time in the deep zones
   February in 1969
   3.2. Increase with towing time in the shallow zones and decrease with towing time in the deep zones
   September in 1969
4. Increase of catch with depth
   November in 1969
5. Different trend of catch-depth relation according to the time class, no clear relation to the towing time
   October in 1969 and April in 1970
6. Sharp decrease of catch with towing time
   May of 1969
7. Small variation of catch relating neither to the depth nor to the towing time
   July and August in 1969, and March in 1970

These results are summarized, and it may be said as follows: In general, it was hard to find any clear bathymetric change of the amount of catch by the towings of the same time length.

Discussion

The clearest result found in the present report was that concerning with the relation between the amount of catch and the length of towing time observable among the records of the towings in the same depth zones of the same grounds on the same months. In the comparison of the regression lines of the amount of catch by a towing on the length of towing time, the lines were classified according as the regression coefficient was 1) large negative, 2) small, and 3) large positive. In the equations with the large negative coefficient, the amount of catch per minute of towing shows a sharp decrease in accordance with the length of towing time. And this pattern seemed to be not efficient because this fact resulted in the boat conducting the long towings over the grounds of low profitability and conducting the towings of short time over the grounds of high profitability. Today, the modern factory trawlers are equipped with the fish detecting instrument of excellent performance like the echo-sounder capable of detecting the schools on deep grounds, and they can attack selectively the directly detected schools. Accordingly, the mechanism of occurrence of this seemingly inefficient pattern may be due to any or all of the following three reasons: They are 1) the efficiency of net in relation to the catch therein, 2) the administration of the hands working in the plant, and 3) the distribution of the fishable population relating to time and space.

The first reason is as follows: The over packed fish in the codend or in the net body reduces the fishing efficiency of the net. Accordingly, it is necessary to take up the catch frequently in the grounds of high density and the boat repeats the frequent towings of short time, while there is no need to do so in the ground of low density. This results in the above-mentioned work pattern. However, there remains a question as to the fact that the boat fished over the grounds of low density over many hours. The second reason has a very close relation to the daily rhythmic change of the behavior pattern of the objective fish and will be shown below. The density of the fishable population varies according to the time and space. Among the third reasons, the evaluation differs according as the variation is relating to the space or to the time. As above-mentioned, the boat is equipped with the excellent fish detecting instrument. Accordingly, it is hardly convincible to tow the net over many hours in the grounds of low profitability, if the density variation were the spatial origin which is avoidable by our effort. The length of towing time showed a large variation in all the seasons in all the depth zones. This fact suggested that the variation of the length of towing time, i.e. that of the density of the objective fish, should be inavoidable regardless of our effort. One of the most probable reasons of causing the inavoidable density variation is that relating to the time, i.e. relating to the daily rhythmic change of the behavior pattern of the objectives. The Alaska pollack swims near the sea bed in the daytime and floats up at night pursuing the prey, planktonic animals. The trawler can catch only the fish living very closely to the sea bed. Accordingly, it is easy to catch the Alaska pollack in the daytime and it is hard to do so at night. This behavior pattern of the objective fish makes the boat tow her net over many hours at night and yield a poor catch while the boat repeat towings of short time in the daytime and yield good catch, for the purpose of not only working at high efficiency but also making the crew take rest over sufficient hours at night and work mainly in the daytime. All the above-mentioned consideration showed that the evaluation of the pattern showing a sharp decrease of catch by a towing in accordance with the length of towing time differs according as the variation is relating to the space or relating to the daily rhythmic change of the behavior pattern of the objectives. It is, accordingly, necessary to examine the daily rhythmic change of the catch, the length of towing time, and the relation between them, for the purpose of finding out whether this seemingly inefficient work pattern is convincible or not.

The regression line with small coefficient is the type observable as frequently as that with the large negative one. In this type, the boat yields similar amount of catch by a towing regardless of its length, but the amount of catch per minute of towing decreases in accordance with the length of towing time, although the decrease is less severer in this type than in the former one. And the mechanism of occurrence and the evaluation of this type are similar to those of the former one. The difference of this type from the former one was mainly due to the good catch by long towings. Namely, the decline of the density of the fishable population for the long towing is smaller in this type than in the former one. This fact hinted that the distribution of these types shows a seasonal change. However, it was hard to find any fact in support of this suggestion. One of the clearest findings in regard to the distributional relation of these types was the bathymetric segregation. This type was found in the zones deeper than 300 m and the former one was mainly in the zones shallower than this depth. This fact may be either or both of the biological reasons and the technical ones. One of the most probable reasons in the former group is as follows: The daily rhythmic difference of the density should be large in the zones shallower than 300 m while that was small in the zones deeper than this depth. This possibility should be examined in the succeeding report. The latter is as follows: In the modern trawling, the boat attacks selectively the directly detected dense schools. The boat studied here fished mainly in the zones from 150 to 400 m deep especially frequently in the zones from 200 to 350 m deep. The boat scouts the schools along zigzag course across isobaths, and finds the dense schools frequently in the intermediate depth zones, as shown in the bathymetric change of the number of towings, and attacks them. Sometimes, she finds the dense schools near the turning points and attacks them. When she can not find any profitable school in all the depth zones, it is more probable to fish in the intermediate depth zones, i.e. in the zone of the highest possibility of encountering the dense school. This caused the decline of the catch by the long towings in the intermediate depth zones.

The regression line with large positive coefficient was the type observable least frequently, and was found in the months showing irregular variations of the type and the catch according to the depth. In this type, the amount of catch per minute of towing shows different trends according to the value of b_0, although the amount of catch by a towing increases in accordance with the length of towing time regardless of the value of

b_0. When b_0 is positive, the catch by a short towing is not very poor, and that per minute of towing decreases very gradually in accordance with the length of towing time. When b_0 is negative, the amount of catch by a short towing is extremely poor, and that per minute of towing increases sharply in accordance with the length of towing time. In regard to the former sub-type, the discussion is similar to that of the other types. For the latter sub-type, there is no need to give discussion in respect of the change of the amount of catch per minute of towing. However, there remains a doubt as to the merit of the long towing and the reason of attacking the population of low profitability. The long towing brings the boat good catch. However, the catch by a long towing is more severely damaged than that by short towing. The catch was not processed into the frozen product keeping its outlook but was processed into the minced one mashing its outlook, and the damage in outlook was less important but high freshness is also needed as the material of the minced product. Abundant supply of the material fish at long intervals is better than the frequent supply of small quantity of fish only under the sufficient carry over of the material fish or for the plant requiring an interval supply of a large quantity of materials; otherwise, it is hard to say that the long towing is reasonable. However, the plant requires unintermittent supply of small quantity of material fish. In addition, the rise in the amount of catch per minute of towing by long towing yields better results only when the dense school is hardly found out. Accordingly, the evaluation of this sub-type differs according as the long towing is reasonable. And it is also necessary to examine the daily rhythmic change of the catch pattern. This type was found mainly on the months showing irregular variations of the type and catch according to the depth zone during the season of long towing (November in 1969 and February in 1970). The difference of the type was mainly due to that of the catch by the towings of short or intermediate time length, and the similar amount of catch was yielded by the long towings. And it is hard to give much importance on the variation of the type, when the distribution of the records along the time axis (x axis) in Fig. 1 is taken into consideration.

One of the principal aims of the present report was to show the bathymetric change of the amount of catch after elimination of the influence of the different length of towing time. However, the amount of catch did not show any significant regression on the depth in 87% of the groups of records in the same grounds on the same months by the towings of the same time length; in other words, the amount of catch did not show any clear bathymetric change. This may be because of the following modification due to the technical reason: The modern factory trawler attacks mainly the directly detected dense schools, and the length of towing time was adjusted according to the density of the objective fish. Accordingly, it is natural that the amount of catch by a towing of the same time length did not show any clear bathymetric difference, even when the density of the objective schools showed a clear bathymetric difference. The echogram of the same object differs according to the depth. The towing resistance of the same net with the same amount of catch therein more or less differs according to the depth. Accordingly, if some types of the bathymetric change of the amount of catch by a towing of the same time length were found out, they may be due to the inadequate understanding of the above-mentioned differences.

The other findings from Table 3 and Fig. 2 were 1) somewhat clear difference of the amount of catch according to the length of towing time, 2) the different trend of catch-depth relation according to the time class, and 3) discrepancies of the results according to the methods of analysis. In Fig. 2, somewhat clear trends of the change of the amount of catch with the length of towing time were found out in some of the months. However, the similar results to those of Fig. 1 were found only on January, February, September in 1969, and March in 1970. For the other months, some discrepancies were found out between the impression of these figures. This fact is due to the following reasons: In Fig. 1, some depth zones of insufficient sample size were not illustrated, the different sample size according to the depth zone and the distribution of the samples along the time axis (x axis) were hardly taken into account. And the different importance of the lines and the parts within a line due to the distribution of the samples were not taken into account. Some of the time classes of insufficient sample size were not illustrated in Fig. 2, and the different sample size according to the time class was hardly taken into account, although the distribution of the samples within a line was taken into account. These facts caused the seeming discrepancies of the results. However, these figures were the results of the examinations on the same records from the different points of view; and it is natural that these figures show the different sections of the feature of the Alaska pollack trawling. And no importance should be attached to the other facts than their principal aims.

The discrepancies of the results of the multiple linear regression and the latter two methods are mainly due to 1) the different relation between the amount of catch and one of the independent variables according to the other, 2) the distribution of the records in respect of either of the independent variables, and 3) the presence of the quadratic or higher order regression of the amount of catch on either of the independent variables. Accordingly, the former method is effective to find an outline, and the latter examinations are needed in the case with high possibility of the complicated relation among these factors like the present case.

Summary

In the modern trawling, the boat attacks selectively mainly the directly detected dense schools. And the bathymetric difference of the density of the objectives was shown by that of the number of towings, but the results were qualitative. The different relation between the amount of catch by a towing and the length of towing time according to the depth and the season and the different length of towing time prevented us from adopting the amount of catch per unit hour of towing as representing the bathymetric change of the density and its seasonal change. For the purpose of representing the bathymetric change of the density of the fishable population, the multiple linear regression equations,

the quadratic and linear regression ones of the amount of catch either on the length of towing time after stratification of the records according to the trawled depth or on the depth after stratification of the records according to the length of towing time, were estimated, and those in the same month-ground groups were compared with one another. And the following results were obtained:

1. The multiple linear regression equations revealed that the catch in the winter months increased in accordance with the trawled depth and that by the towings of short time was better than that by long towings.

2. The amount of catch in the three-fourths of the strata (month-ground-depth zone) of the records did not show any significant quadratic and linear regression on the length of towing time (Similar amount of catch was yielded by a towing regardless of its time length).

3. Whether the regression coefficient was significant or not being left aside, the decreasing trend of the catch in accordance with the length of towing time was found in the zones shallower than 300 m and the trend of similar amount of catch regardless of the length of towing time was found in the zones deeper than this depth. And the increasing trend in accordance with the towing time was found only in the months showing an irregular variation of the type.

4. The amount of catch by a towing in the 87% of the strata (same ground, same months, same length of towing time) of the records did not show any significant quadratic and linear regression on the depth; namely, similar amount of catch was yielded by the towings of the same time length regardless of the depth in the 87% of the strata.

5. It was hard to consider that the above-mentioned findings directly showed the different density relating to space. And it was probable that they showed the results of the technical modification of the daily rhythmic change of the density of the fishable population.

Reference

1. MAÉDA, H., 1972: *This Jour.*, 21, 1–20.