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An Analysis of the Catch Records of the Alaska Pollack Trawling—V.*

The Bathymetric and Daily Rhythmic Change of the Length of Towing Time

By
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The recent advances in the fishing techniques changed completely the work pattern of boats in many fisheries. The trawling for roundfishes on rough ground is one of the representatives of the fisheries developed recently as the results of application of modern techniques. The well-equipped large stern ramp factory trawler usually attacked selectively the schools of the Alaska pollack detected directly, adjusting the length of towing time according to the distribution of the objective fish and the estimated catch in the codend during towing, for the purpose of working at high efficiency. These changes in the work pattern resulted in large variation of the length of towing time and small variation of the amount of catch by a towing. And the same facts made it difficult to find the bathymetric distribution of the objective fish through that of the amount of catch by a towing[1]. And the seasonal and bathymetric differences in the catch-time relation made it difficult to use the amount of catch per unit hour of towing for indicating variation of density of the population in trawlable state[2]. The other fact making the analysis difficult was the clear daily rhythmic change of the work pattern and the catch by a towing[3]. The variation of the length of towing time was still large after the threefold stratification of the records according to the hour of shooting the gear, the month, and the ground; but the amount of catch by a towing did not show any significant quadratic and linear regressions on the length of towing time[4]. These facts suggested the possibility of the length of towing time applicable to representing the change not only of the work pattern but also of the density of the objective fish in trawlable state instead of the amount of catch either by a towing or by unit hour of towing. In the present report, accordingly, the time-depth relations

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after the threefold stratification of the records according to the hour, the month, and the ground, were examined, and those of the different hours in the same months or those of the same hours in the different months were compared with one another, for the purpose of clarifying the seasonal–daily rhythmic–bathymetric change not only of the work pattern but also of the probable density of the population in the trawlable state.

Material and Method

The same materials as those of the preceding reports[1)-4)] of this series were used in the present report, too. They were the catch records of 2,736 towings (after removal of the records of 54 accidental towings and those of 342 towings occupied more than 10% by other fish than the Alaska pollack) by a minced fish stern ramp factory trawler of about 4,000 gross tons during the season from Dec. 23 in 1968 to May 2 in 1970 along the outer edge of the continental shelf of the Eastern Bering Sea.

In the original records, the echo-sounded depth was recorded in meters, and the length of towing time was in minutes. The former was, however, aggregated into the classes of the nearest 25-m intervals and the latter was into the classes of the nearest 5-minute intervals, because the accuracy of the measurement and the distribution were taken into account. The records were stratified according to the month, the ground shown in Fig. 1 of the first report[1)], and the hour of shooting the net into the classes of the nearest 2-hour intervals, because the distribution and the density of the population in trawlable state differ with these factors. After the exclusion of the strata consisted of less than five towings, the quadratic and linear regression equations of the length of towing time on the echo-sounded depth observable in respective hour-month-ground groups of the records were estimated. And the seasonal and daily rhythmic changes of the bathymetric difference of the length of towing time were examined through the comparison of the regression lines of the same hours in the different months or those of the different hours in the same months.

Results

1. The quadratic and linear regressions

If the insignificance of the regression of the amount of catch by a towing on the length of towing time[4)] means that the length of towing time is inversely proportional to the density, and if the population density is highest on the sea floor of the intermediate depth and decreases in accordance with the difference of the trawled depth from this zone, the length of towing time shows a concave relation to the trawled depth. The results of the present examination, however, did not show any clear trends in respect of the quadratic regression of the length of towing time on the depth: as shown in Table 1, the quadratic regression coefficient a_2 took positive value in about a half of

Table 1. The estimated quadratic and linear regression equations of the length of towing time on the trawled depth.

	Hour	a_0	a_1	a_2	F_2	b_0	b_1	F_1	n
Jan. '69	1	332	−2.80	0.0073	2.65	60	0.09	0.23	16
	3	546	−5.49	0.0150	10.32**	44	0.14	0.41	14
	5	−358	4.53	−0.0118	0.58	19	0.25	0.72	16
	7	524	−4.83	0.0119	3.03	87	−0.16	0.87	16
	9	171	−1.25	0.0026	2.48	67	−0.17	7.88**	28
	11	93	−0.60	0.0013	1.24	42	−0.06	1.67	26
	13	61	−0.15	0.0000	0.00	61	−0.14	5.45*	21
	15	146	−0.74	0.0014	0.26	86	−0.15	2.07	25
	17	−564	6.47	−0.0146	1.75	97	−0.10	0.17	9
	19	−510	6.68	−0.0176	1.75	150	−0.33	1.52	7
	21	−538	6.38	−0.0153	4.12	40	0.26	1.90	6
	23	−100	1.77	−0.0039	0.86	47	0.21	1.59	11
Feb.	1	304	−1.61	0.0029	0.32	97	−0.03	0.01	10
	3	9	0.54	−0.0011	0.19	72	0.01	0.00	11
	5	42	0.17	−0.0001	0.01	50	0.10	1.30	10
	7	223	−1.53	0.0030	8.02*	20	0.06	0.69	17
	9	225	−1.58	0.0031	14.45**	15	0.07	1.12	25
	11	105	−0.74	0.0017	1.45	−22	0.22	6.51*	22
	13	39	−0.12	0.0003	0.04	11	0.08	0.76	20
	15	−807	5.78	−0.0095	2.38	28	0.12	0.28	20
	17	−4238	25.65	−0.0380	1.59	−269	1.04	6.52*	8
	19	109	0.19	−0.0008	0.32	157	−0.22	7.46*	9
	21	1031	−5.76	0.0088	0.23	160	−0.20	0.31	6
	23	691	−5.22	0.0105	18.11*	157	−0.34	1.88	6
March	1	316	−1.44	0.0021	1.22	116	−0.12	0.81	20
	3	515	−2.87	0.0045	0.31	−40	0.33	1.98	18
	5	718	−3.87	0.0055	1.08	80	−0.09	0.24	15
	7	−7	0.31	−0.0004	0.01	46	0.01	0.00	22
	9	−372	2.39	−0.0034	1.29	39	0.02	0.03	21
	11	−240	1.75	−0.0027	0.32	77	−0.11	0.77	20
	13	19	0.15	−0.0003	0.01	53	−0.04	0.16	27
	15	452	−2.39	0.0036	0.35	−7	0.19	0.59	17
	17	430	−1.82	0.0022	0.02	132	−0.18	0.22	14
	19	−281	2.35	−0.0037	0.17	175	−0.26	0.80	12
	21	270	−1.11	0.0016	0.04	72	0.02	0.01	17
	23	1144	−6.13	0.0087	0.25	147	−0.21	0.48	9

Table 1 . — (Cont'd)

	Hour	a_0	a_1	a_2	F_2	b_0	b_1	F_1	n
April	1								
	3								
	5	711	−3.51	0.0047	0.56	175	−0.30	3.10	10
	7	979	−5.54	0.0081	4.56	57	−0.03	0.03	10
	9	518	−2.74	0.0039	1.40	63	−0.05	0.15	12
	11	703	−3.75	0.0052	1.61	101	−0.17	1.33	9
	13	1334	−7.58	0.0110	5.88*	55	−0.01	0.00	12
	15	56	−0.04	0.0001	0.00	49	0.00	0.00	10
	17	2115	−11.62	0.0163	1.98	109	−0.11	0.11	7
	19								
	21								
	23								
May	1					120	−0.10	0.09	5
	3	−531	4.44	−0.0079	19.26**	36	0.15	0.57	8
	5	28	0.28	−0.0004	0.02	48	0.10	0.42	10
	7	−787	5.90	−0.0098	1.58	26	0.19	0.47	6
	9	173	−1.50	0.0044	7.70	0	0.33	7.52*	7
	11	31	0.15	0.0003	0.00	12	0.31	2.67	8
	13	−115	1.97	−0.0049	0.13	110	−0.15	0.21	9
	15	111	−0.16	0.0000	0.00	110	−0.15	0.71	9
	17	645	−3.92	0.0072	0.42	141	−0.09	0.17	6
	19	−346	3.40	−0.0061	6.13	67	0.18	1.64	6
	21	365	−2.10	0.0040	0.04	152	−0.24	0.47	6
	23	−61	1.26	−0.0023	1.14	29	0.29	6.44	6
July	1	128	0.08	−0.0004	0.00	158	−0.14	0.71	12
	3	260	−1.24	0.0025	0.61	33	0.29	1.91	16
	5	1456	−9.54	0.0166	9.24**	114	−0.04	0.02	18
	7	−114	1.35	−0.0021	0.45	43	0.18	2.60	21
	9	−135	1.66	−0.0030	0.61	84	0.01	0.00	21
	11	372	−1.96	0.0032	0.59	149	−0.25	1.86	24
	13	91	−0.24	0.0007	0.01	41	0.14	0.25	23
	15	−204	2.23	−0.0042	0.27	97	−0.06	0.06	16
	17	1716	−11.89	0.0214	11.90**	165	−0.28	1.63	21
	19	904	−6.41	0.0125	0.89	54	0.16	0.30	15
	21	141	−0.31	0.0007	0.02	81	0.09	0.18	16
	23	233	−0.82	0.0013	0.02	140	−0.13	0.33	16

Table 1 . — (Cont'd)

Month	Hour	a_0	a_1	a_2	F_2	b_0	b_1	F_1	n
Aug.	1	−119	1.66	−0.0028	5.44*	48	0.25	8.84**	19
	3	−1118	8.77	−0.0155	10.38**	107	−0.02	0.01	16
	5	41	0.53	−0.0013	0.12	127	−0.16	1.14	20
	7	−494	4.50	−0.0087	9.76**	63	0.07	0.24	21
	9	−139	1.59	−0.0028	0.88	36	0.16	1.77	21
	11	−214	2.32	−0.0043	2.79	99	−0.03	0.07	16
	13	−712	6.30	−0.0121	13.95**	131	−0.14	1.10	23
	15	−349	3.35	−0.0062	6.59*	92	−0.00	0.00	16
	17	−263	2.53	−0.0043	3.16	35	0.22	4.63*	23
	19	268	−1.26	0.0023	0.73	119	−0.07	0.35	19
	21	220	−1.29	0.0031	1.83	38	0.24	6.15*	20
	23	−530	4.74	−0.0085	5.31*	5	0.42	4.51	16
Sept.	1	−281	2.56	−0.0042	3.32	24	0.27	5.83*	22
	3	39	0.29	−0.0002	0.01	55	0.17	3.97	18
	5	249	−1.37	0.0028	1.22	57	0.11	1.08	15
	7	249	−1.05	0.0015	0.39	142	−0.23	6.11*	19
	9	129	−0.43	0.0009	0.09	60	0.08	0.32	26
	11	−225	2.69	−0.0058	1.07	219	−0.54	8.80**	21
	13	118	−0.25	0.0005	0.04	76	0.04	0.14	24
	15	165	−0.41	0.0004	0.02	135	−0.18	1.75	22
	17	270	−1.31	0.0024	0.66	94	0.00	0.00	22
	19	−84	1.21	−0.0018	1.04	50	0.21	5.95*	16
	21	−160	2.53	−0.0059	7.85*	159	−0.27	3.17	13
	23	−154	1.84	−0.0033	2.17	85	0.03	0.07	17
Oct.	1	−347	3.15	−0.0054	4.13	119	−0.06	0.31	19
	3	−765	5.74	−0.0094	3.42	40	0.22	2.09	16
	5	146	−0.55	0.0014	0.12	36	0.24	2.91	17
	7	251	−1.33	0.0026	0.88	62	0.09	0.86	15
	9	−78	1.08	−0.0017	0.32	57	0.12	1.05	24
	11	−232	2.02	−0.0031	0.85	27	0.20	2.14	18
	13	167	−0.34	0.0003	0.00	139	−0.15	0.39	16
	15	−13	0.78	−0.0014	0.20	102	−0.01	0.01	20
	17	−145	1.66	−0.0028	0.69	81	0.06	0.32	17
	19	329	−1.58	0.0026	1.64	134	−0.13	1.86	13
	21	356	−1.93	0.0035	1.09	64	0.11	0.94	17
	23	−794	5.77	−0.0092	0.96	12	0.28	1.57	17

Table 1 . — (Cont'd)

	Hour	a_0	a_1	a_2	F_2	b_0	b_1	F_1	n
Nov.	1	799	−5.95	0.0128	1.98	82	0.12	0.28	11
	3	214	−1.17	0.0029	0.10	43	0.25	1.30	14
	5	−177	2.18	−0.0042	1.93	28	0.27	2.25	8
	7	84	−0.09	0.0005	0.04	59	0.12	1.14	18
	9	39	0.43	−0.0008	0.10	81	0.07	0.23	13
	11	159	−0.58	0.0016	0.95	80	0.14	3.16	15
	13	−92	1.57	−0.0029	0.51	59	0.21	1.22	12
	15	159	−1.13	0.0035	2.07	6	0.38	6.66*	11
	17	234	−0.99	0.0020	0.26	150	−0.16	1.08	10
	19	41	0.48	−0.0008	0.06	69	0.18	1.52	7
	21	−115	1.73	−0.0034	1.15	34	0.28	4.87	11
	23	3267	−26.00	0.0533	25.00*	0	0.50	1.67	5
Jan.' 70	1	60	0.62	−0.0018	0.26	130	−0.13	1.48	11
	3	300	−2.09	0.0051	1.14	99	0.02	0.03	11
	5	154	−0.46	0.0012	0.28	102	0.06	0.36	12
	7	171	−1.00	0.0026	0.50	77	0.01	0.01	17
	9	291	−1.97	0.0044	4.18	73	0.05	0.16	19
	11	127	−0.54	0.0012	0.47	73	−0.01	0.01	16
	13	−118	2.07	−0.0053	0.86	67	0.04	0.05	11
	15	−75	1.39	−0.0027	0.18	15	0.39	4.33	14
	17	−2	1.07	−0.0025	0.70	97	0.05	0.21	11
	19	40	0.70	−0.0016	1.51	117	−0.04	0.32	11
	21	55	0.70	−0.0017	1.25	125	−0.02	0.18	15
	23	34	1.04	−0.0032	0.92	155	−0.26	4.81	10
Feb.	1	21	0.70	−0.0012	0.98	130	−0.06	0.17	13
	3	119	−0.29	0.0009	0.18	63	0.18	1.07	10
	5	−244	2.30	−0.0035	13.88**	140	−0.09	0.71	17
	7	−36	0.80	−0.0012	1.85	55	0.10	0.74	13
	9	75	0.18	−0.0003	0.45	101	−0.02	0.13	17
	11	34	0.47	−0.0008	0.41	85	0.04	0.24	12
	13	139	−0.29	0.0005	0.32	103	−0.03	0.08	15
	15	93	−0.05	0.0001	0.00	85	0.01	0.01	13
	17	125	−0.01	−0.0001	0.02	134	−0.07	0.75	17
	19	202	−0.49	0.0007	0.42	131	−0.04	0.19	10
	21	−42	1.18	−0.0019	5.70*	129	0.00	0.00	12
	23	161	−0.19	0.0002	0.07	137	−0.04	0.63	12

Table 1 . — (Cont'd)

	Hour	a_0	a_1	a_2	F_2	b_0	b_1	F_1	n
March	1	−515	3.45	−0.0047	5.51	210	−0.27	4.03	10
	3	−381	2.72	−0.0037	2.14	112	−0.04	0.04	10
	5	−494	3.02	−0.0038	3.10	25	0.17	1.90	20
	7	−1014	6.45	−0.0095	0.86	25	0.15	0.41	22
	9	−17	0.30	−0.0002	0.01	3	0.19	4.14	24
	11	1084	−6.39	0.0100	2.78	−62	0.39	5.76*	21
	13	1011	−5.76	0.0087	3.17	22	0.12	0.44	26
	15	417	−1.88	0.0025	0.21	135	−0.20	1.08	21
	17	−370	2.67	−0.0039	0.42	82	0.01	0.00	18
	19	−63	1.29	−0.0022	0.39	129	−0.02	0.02	9
	21	228	−0.69	0.0009	0.22	136	−0.10	0.59	12
	23	129	−0.00	−0.0002	0.00	155	−0.16	0.82	9
April	1	324	−1.79	0.0037	1.89	155	−0.14	2.32	9
	3	39	0.59	−0.0012	0.61	99	0.03	0.20	11
	5	130	−0.31	0.0004	0.06	110	−0.12	2.94	22
	7	17	0.48	−0.0008	0.47	59	0.09	2.71	24
	9	86	0.01	−0.0001	0.01	92	−0.04	0.55	24
	11	35	0.52	−0.0011	0.65	100	−0.05	0.44	18
	13	116	−0.04	−0.0002	0.02	127	−0.14	2.72	19
	15	111	−0.29	0.0006	0.25	71	0.05	0.30	19
	17	206	−0.66	0.0009	0.26	156	−0.20	4.26	21
	19	233	−1.01	0.0020	0.65	141	−0.11	1.30	13
	21	133	0.03	−0.0003	0.01	148	−0.12	3.57	8
	23	213	−0.89	0.0019	0.93	136	−0.06	0.65	12

Note:

x....... The trawled depth (in meters)

y....... The length of towing time (in minutes)

$y = a_0 + a_1 x + a_2 x^2$

$y = b_0 + b_1 x$

n....... The number of the records in the stratum

F_i...... The Snedecor's F-value for the i-th order regression coefficient in the i-th order regression equation, with 1 and (n-i-1) degrees of freedom

* Significant at 0.05 level ** Significant at 0.01 level

the strata and negative one in the other half. The coefficients in the eight strata out of the 81 ones of the former group and that in the 10 strata out of the 81 ones of the latter group were significant at 0.05 level. The presence of the significant coefficients at 0.05 level in about 5% of the strata is worth while giving considerations only when their distributions show daily rhythmic or seasonal change; otherwise, there is no need to give much importance on their presence. Either the significantly positive coefficient or the significantly negative one was distributed throughout the hour groups. The significantly positive one seemed to be distributed mainly in the earlier half of the season and the significantly negative one was in August. It was hard to say, however, that the rate of the strata taking the positive coefficient showed daily rhythmic change or seasonal one: for the daily rhythmic changes, the Snedecor's F-values for the i-th order coefficient (F_i) in the i-th order regression equation of the rate (after the arc sine transformation) on the hour were as follows: $F_3 = 0.01$, $F_2 = 3.38$, and $F_1 = 0.31$; $n = 12$; with 1 and $(n - i - 1)$ degrees of freedom. For the seasonal change, those of the rate on the month counted from January in 1969 were as follows: $F_3 = 0.88$, $F_2 = 0.07$, and $F_1 = 2.56$; $n = 14$. And those of the rate on the month counted from January (the difference of the year being neglected) were as follows: $F_3 = 1.10$, $F_2 = 0.23$, and $F_1 = 0.16$; $n = 14$.

Before concluding that these results meant that the length of towing time in the same hour of the same month did not show any clear bathymetric change, the following facts necessitated further consideration: the time-depth relation within the applicable range differs according not only to the quadratic coefficient but also to the other coefficients and the extent of the applicable range. The trawled depth showed a seasonal change[1), although this did not show any clear daily rhythmic change[3). The boat fished on a little deeper grounds during late winter and early spring than in the other seasons. The variation was small in March and April in 1969, and large in January, February, and November in 1969 and January, February, and April in 1970. Accordingly, the general trends shown by the estimated quadratic regression equations for respective hour-month-ground strata were classified into the types shown in Fig. 1 according to either concave or convex and according to the depth of the minimum (or the maximum) of the towing time in relation to the applicable range. And the seasonal and daily rhythmic change of the general trend is shown in Table 2. This table revealed the following facts: the insignificance of the quadratic regression coefficient only in the five strata out of the 162 ones was due to the small bathymetric change of the length of towing time. That in the 89 strata was due to the strong bias of the depth showing either the maximum or the minimum of the towing time in either of the directions (shallower or deeper than the applicable range). The shortening trend of towing time in accordance with the trawled depth was found in the 24 concave curves and in the 20 convex ones; the mainly shortening and partly elongating trend was found in the 17 concave curves and in the 12 convex ones; the mainly elongating and partly shortening trend was found in the 16 concave curves and in the 23 convex ones; and the elongating trend was found in the 21 concave curves and in the 24 convex ones. The shortening trend was less frequently found in the summer half of the year (May to November), especially in the morning, and the elongating one was less frequently found at night in the winter half (January to April).

The examinations on the linear regression showed similar results: the coefficient in

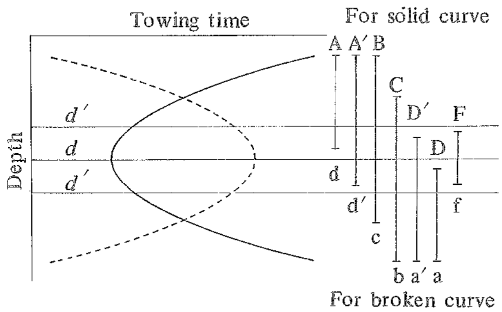

Fig. 1. Classification of the time-depth relation in respect of the applicable depth range and the estimated depth showing the maximum or the minimum of the towing time.

d ····the depth showing the maximum or minimum of the towing time

d′ ····the towing time at this depth being 0.9 of the maximum towing time or 1.1 of the minimum one

Respective types are defined as follows:

The depth showing the minimum of towing time

Concave
- Deeper than the deepest limit of the applicable range .... A
- Between the median and the deepest limit
  - The difference of the length of towing time at the deepest limit from the minimum of towing time being less than 10 % of the latter .... A′
  - The difference being more than 10 % .... B
- Between the shallowest limit and median
  - The difference of the length of towing time at the shallowest limit from the minimum of towing time being more than 10 % of the latter C
  - The difference being less than 10 % .... D′
- Shallower than the shallowest limit .... D
- The difference of the towing time at either of the limits of the applicable range from the minimum of the towing time being less than 10 % of the latter .... F

The depth showing the maximum of towing time

Convex
- Shallower than the shallowest limit .... a
- Between the shallowest limit and the median
  - The difference of the length of towing time at the shallowest limit from the maximum towing time being less than 10 % of the latter .... a′
  - The difference being more than 10 % .... b
- Between the median and the deepest limit
  - The difference of the length of towing time at the deepest limit from the maximum of towing time being more than 10 % of the latter c
  - The difference being less than 10 % .... d′
- Deeper than the deepest limit .... d
- The difference of the towing time at either of the limits of the applicable range from the maximum of towing time being less than 10 % of the latter .... f

$a_1<0 \quad 0<a_2< \quad 0.00005$ .... (A)

$a_1>0 \quad 0>a_2> \quad -0.00005$ .... (D)

the 10 strata was significantly positive, that in the 76 strata was insignificantly positive, that in the 72 strata was insignificantly negative, and that in the five strata was significantly negative. The significantly positive coefficients were scattering over throughout the season and throughout the hour; while the significantly negative ones were in

Table 2. The seasonal and daily rhythmic change of the time-depth relation within the applicable range.

Season	The hour of shooting the net: 1	3	5	7	9	11	13	15	17	19	21	23	AA′ aa′ (A)	B	b	C	c	DD′ dd′ (D)	Ff
Jan. '69	C(150) (192)	C(125)* (183)	c(75) 192	B(100) (203)	B(150) (240)	B(175) (231)	(A)(150)	A′(175) (264)	b(150) 222	b(100) 190	c(100) 208	d′(150) 227	2	3	2	2	2	1	
Feb.	B(150) (278)	b(200) 245	d(175) 850	C(175)* (255)	B(200)* (255)	C(175) (218)	D(150) (200)	c(100) 304	d′(50) 338	a(200) 119	A′(75) (327)	B(150)* (249)	2	3	1	2	1	3	
March	A′(200) (343)	D′(100) (319)	B(125) (352)	d′(100) 388	c(150) 351	a′(100) 324	a(125) 250	D′(125) (332)	A(75) (414)	a′(100) 318	F(100) (347)	A′(75) (352)	6	1			1	3	1
April			A′(125) (373)	B(125) (342)	B(125) (351)	B(125) (361)	B(125)* (345)	F(125) (200)	B(100) (356)				1	5					1
May		c(150)* 281	d(150) 350	c(125) 301	C(175) (170)	D(125) (−250)	a′(75) 201	(A)(125)	A′(75) (272)	c(125) 279	A′(75) (263)	d′(175) 274	4			1	3	3	
July	a(100) 100	D′(175) (248)	C(125)* (287)	d′(125) 321	c(150) 277	A′(150) (306)	D(125) (171)	c(125) 265	B(100)* (278)	C(75) (256)	D(125) (221)	A′(100) (315)	3	1		2	2	4	
Aug.	d′(200)* 296	b(125)* 283	a′(125) 204	b(125)* 259	d′(150) 284	b(150) 270	b(125)* 260	c(175)* 270	c(150) 294	A′(150) (274)	D′(150) (208)	c(150)* 279	2		4		3	3	
Sept.	d′(150) 305	d(150) 725	D′(125) (245)	A(125) (350)	D′(150) (239)	a′(100) 232	D′(150) (250)	A(150) (513)	C(150) (273)	d′(150) 336	b(175)* 214	c(150) 279	3		1	1	1	6	
Oct.	c(125) 292	c(100) 305	D(125) (196)	D′(125) (256)	d′(125) 318	d′(125) 326	A(100) (567)	f(125) 279	d′(125) 296	A′(150) (304)	C(125) (276)	c(100) 314	2			1	3	5	1
Nov.	C(75) (232)	D′(75) (202)	d′(150) 260	D(175) (90)	d′(175) 269	D′(175) (181)	d′(150) 271	D′(175) (161)	A′(125) (248)	d(150) 300	d′(125) 254	C(50)* (244)	1			2		9	
Jan. '70	a′(150) 172	B(150) (205)	D′(200) (192)	C(150) (192)	C(175) (224)	B(175) (225)	c(125) 195	d(125) 257	c(175) 214	b(225) 219	a′(175) 206	a′(150) 163	3	2	1	2	2	2	
Feb.	b(300) 292	D′(200) (161)	b(275)* 329	c(350) 333	f(300) 300	d′(250) 294	C(300) (290)	F(225) (250)	a(325) −50	A′(250) (350)	c(300)* 311	A(200) (475)	3		2	1	2	2	2
March	a′(150) 367	b(200) 368	c(175) 397	c(75) 339	d(200) 750	D′(100) (320)	C(125) (331)	A′(125) (376)	c(125) 342	a′(150) 293	A′(175) (383)	a(150) 0	5		1	1	3	2	
April	B(150) (242)	a′(200) 246	A(200) (388)	d′(200) 300	a(225) 50	a′(225) 236	a(250) −100	D′(250) (242)	A(225) (367)	C(175) (253)	a(150) 50	B(200) (234)	7	2		1		2	
Jan. to April: 1) AA′aa′(A)	3	1	2		1	2	3	2	3	4	4	4							
2) B	2	1	1	2	3	3	1		1			2							
3) b	1	2	1						1	2									
1)+2)+3)	6	4	4	2	4	5	4	2	5	6	4	6							
4) C	1	1		2	1	1	2			1									
5) c			2	2	1		1	1	2		2								
6) DD′dd′(D)		2	2	2	1	2	1	3	1			1							
4)+5)+6)	1	3	4	6	3	3	4	4	3	1	2	1							
May to Nov.: 7) AA′aa′(A)	1		1	1		2	2	2	2	2	1	1							
8) B									1										
9) b		1		1		1	1				1								
7)+8)+9)	1	1	1	2	0	3	3	2	3	2	2	2							
10) C	1		1		1				1	1	1	1							
11) c	1	2		1	1			2	1	1		3							
12) DD′dd′(D)	2	3	4	3	4	3	3	1	1	2	3	1							
10)+11)+12)	4	5	5	4	6	3	3.	3	3	4	4	5							

Legend

Type (shown in the below) → C (125)* ← The quadratic regression coefficient was significant

(183)

(Deepest limit of the applicable range)-(Shallowest one)=125 m
If Gothic, the linear regression coefficient was significant

The depth showing the minimum of towing time
If Roman, out of the applicable range
If without parenthesis, the depth showing the maximum of towing time

The abbreviations of the types are shown in Fig. 1.

the earlier half of the season mainly in the daytime. The rate of the strata taking the positive coefficient (after the arc sine transformation) did not show any daily rhythmic change clearly (F_3 = 4.81, F_2 = 0.15, and F_1 = 1.82; n = 12). That however showed the seasonal change (the regression on the month counted from January in 1969 ... F_3 = 5.50*, F_2 = 2.77, and F_1 = 0.07; n = 14. The regression on the month counted from January neglecting of the year .... F_3 = 0.01, F_2 = 9.00*, and F_1 = 4.91; n = 14). And the rate was lowest in April of 1969 and highest in November. Namely the elongating trend was least frequently found in April and most frequently found in November.

2. The bi-hourly change of the time-depth relation

The quadratic and linear regression coefficients were examined in the preceding section, and the results suggested some clue to the daily rhythmic and seasonal change of the time-depth relation. These examinations were, however, insufficient to clarify the relation, because the variations of the constant and the applicable range were not taken into account in spite of the fact that the relation differs also according to these factors. For the purpose of finding out the bi-hourly change of the estimated time-depth relation within the applicable range, accordingly, those for the different hour groups in the same months were compared with one another with the assistance of Fig. 2, and the following trends were found out: in general, the difference of the length of towing time due to the daily rhythmic change was far larger than the difference due to the bathymetric change. This fact made it hard to find the hourly difference of the trend of the bathymetric change. In January, the trend of short towing in the daytime and long towing at night was clearer on the deep ground than on the shallow one. In consequence, the towing time in the daytime was short and showed a shortening trend in accordance with depth, while that at night was long and showed an elongating trend. In February, the towing time showed the bathymetric change contrary to that found in January. Namely, the hourly change was clearer on the shallow ground than on the deep one; and the towing time was elongated in accordance with depth in the daytime while that was shortened with depth at night. The different results found between January and February may be due to the following reasons: the bathymetric distribution of the records was not taken into account in Fig. 2. The boat fished in the similar depth range in these months. As shown in Fig. 4 of the first report, however, the distribution of the towings in January was biased into near the shallowest limit of the applicable range (150 m), while that in February was into near the deepest one (300 m). Accordingly, it may be said that the results of these months coincided with each other in respect of less clear daily rhythmic change of the length of towing time in the zone fished mainly than in the other zones. In March and April, the boat fished on the deep ground, and the towings were concentrated into the narrow depth range. In consequence, it was hard to find the bathymetric change of the length of towing time. In May, the fishing ground extended over the shallow zones, too. And the elongating trend of the towing time in accordance with depth was found

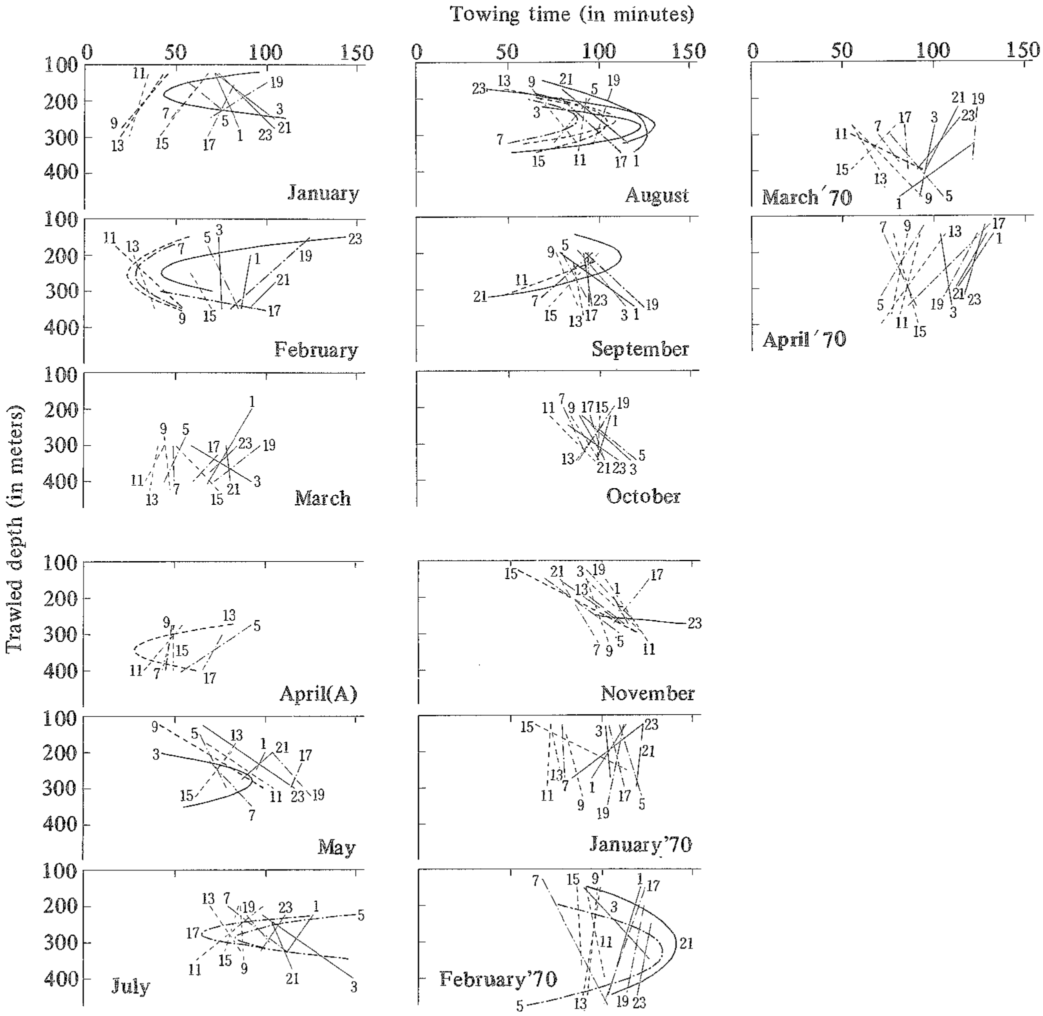

Fig. 2. The bi-hourly change of the time-depth relation.

Note : Curve . . . . .The stratum showing the significant quadratic regression

Thick line . . . . That showing the insignificant quadratic regression but the significant linear one

Thin line . . . . . That showing neither the significant quadratic regression nor the significant linear one

Solid line . . . . .1:00, 3:00, 21:00, and 23:00

Chain line . . . . 5:00, 7:00, 17:00, and 19:00

Broken line . . . 9:00, 11:00, 13:00, and 15:00

The numerals attached the lines are the hour of shooting the net.

out in most of the hour groups covering wide depth range. The time-depth relation changed, however, severely and irregularly in accordance with passing of hour. In July, the bathymetric change was hardly observable because of the narrow depth range, but the daily rhythmic change was observable clearly. August was the month showing the clearest depth regression of the length of towing time. The significant quadratic regression was found in the six hour groups and the significant linear one was in the three groups. The trend of the quadratic regression was, however, contrary to the expectation and showed the convex relation of the length of towing time to the depth. In spite of this fact, the daily rhythmic change coinciding with the expectation was found out. In September, the length of towing time on the shallow ground was similar to one another, regardless of the hour of shooting the net. That on the deep ground showed, however, the change roughly relating to the hour. In consequence, the towing time showed the elongating trend with depth at night and the shortening one in the daytime. In October, the linear regression coefficients in most of the hour groups were positive, although they were insignificant. In November, the fishing ground extended over the shallow grounds, too. And the linear regression coefficients in all the hour groups except one of them were positive, although all the coefficients except one of them were insignificant. The towing time on the deep ground showed small hourly change, and that on the shallow ground changed severely and irregularly in accordance with passing of hour. In January in 1970, the towing time did not show any clear bathymetric change, but showed somewhat clear daily rhythmic change. In February, it was hard to find any clear bathymetric change of the length of towing time, in spite of the fact that the trawled depth showed the widest variation. Somewhat clear trend of daily rhythmic change was however found out. In March, the distribution of the regression lines on the graph showed the daily rhythmic change of the length of towing time and the trawled depth—deep and short in the daytime while shallow and long at night. The towing time showed a shortening trend with depth in the daytime, while that showed an elongating one at night. In April, the length of towing time showed somewhat clear daily rhythmic change, and showed a shortening trend with depth in most of the hour groups, although the regression coefficient was insignificant in all the hour groups.

As above-mentioned, the clearest result of the comparison of the time-depth relations in the different hour groups in the same months was somewhat clear daily rhythmic change of the length of towing time. And, in regard to the bathymetric change of the length of towing time, the present section revealed that either the strata taking the positive coefficient or those taking the negative one were distributed not by chance but their distribution had a relation either to the month or to the hour although the pattern of its daily rhythmic change differed monthly. This fact may make it hard to find any clear results in regard to either the seasonal or daily rhythmic change of their distribution examined in the preceding section. And the months were classified according to the pattern of daily rhythmic change of the time-depth relation into as follows:

1) Shortening with depth in most of the hour groups
May in 1969 and April in 1970
2) Shortening with depth in the daytime while elongating with depth at night
Clearly in January in 1969 Roughly in September
3) Elongating with depth in the daytime while shortening with depth at night
February in 1969 and March in 1970
4) Elongating with depth in most of the hour groups
October and November
5) Significantly convex in a half of the hour groups
August
6) Small bathymetric difference
March, April and July in 1969, January and February in 1970

3. The seasonal change of the time-depth relation

For the purpose of finding out the seasonal-bathymetric change of the length of towing time after elimination of the influence of its daily rhythmic change, the time-depth relations observable in the same hour groups in different months were compared with one another with the assistance of Fig. 3, although the results of the preceding sections and the large seasonal change of the hours of the sunrise and the sunset in high latitudinal waters suggested some difficulties in finding out clear results. This figure revealed that the difference of the length of towing time due to the seasonal change was far larger than that due to the bathymetric change. This fact made it hard to find the seasonal difference in the bathymetric change. The clearest finding was the short towing in the first four months (January to April in 1969). This trend was clear in the daytime but obscure at night. The lines for May in 1969 and March in 1970 showed the intermediate trend between those of the first four months and the other months. When the lines for these months were laid aside consideration, the lines of the same hour groups in different months showed, in some of the hour groups, roughly the similar trend to one another. This was clear in the Hour Groups 3:00, 7:00, and 9:00. This was peculiar finding, because of the following reason: the fishing ground was in high latitudinal waters; and the hours of the sunrise and the sunset show clear seasonal changes; and in these hour groups some of the lines show the relations in the daytime (during summer) while the other show the relations at night (during winter) or dawn or dusk according to the season; in spite of this fact, the time-depth relations of the different months showed the similar trend to one another. In contrast with this, all the lines in the Hour Groups 11:00 and 13:00 and most of the lines in the Hour Groups 15:00 and 17:00 show the relations in the daytime; and all the lines in the Hour Groups 1:00, 21:00, and 23:00 show those at night regardless of the season. However, the time-depth relations in these hour groups varied monthly. The boat fished on deep ground in March, April in 1969, and March in 1970. The towing time in the daytime was longest in November in 1969 and February in 1970. Besides these general trends, the following rough trends were found out in respective hour groups: 1:00 · · · · ·The

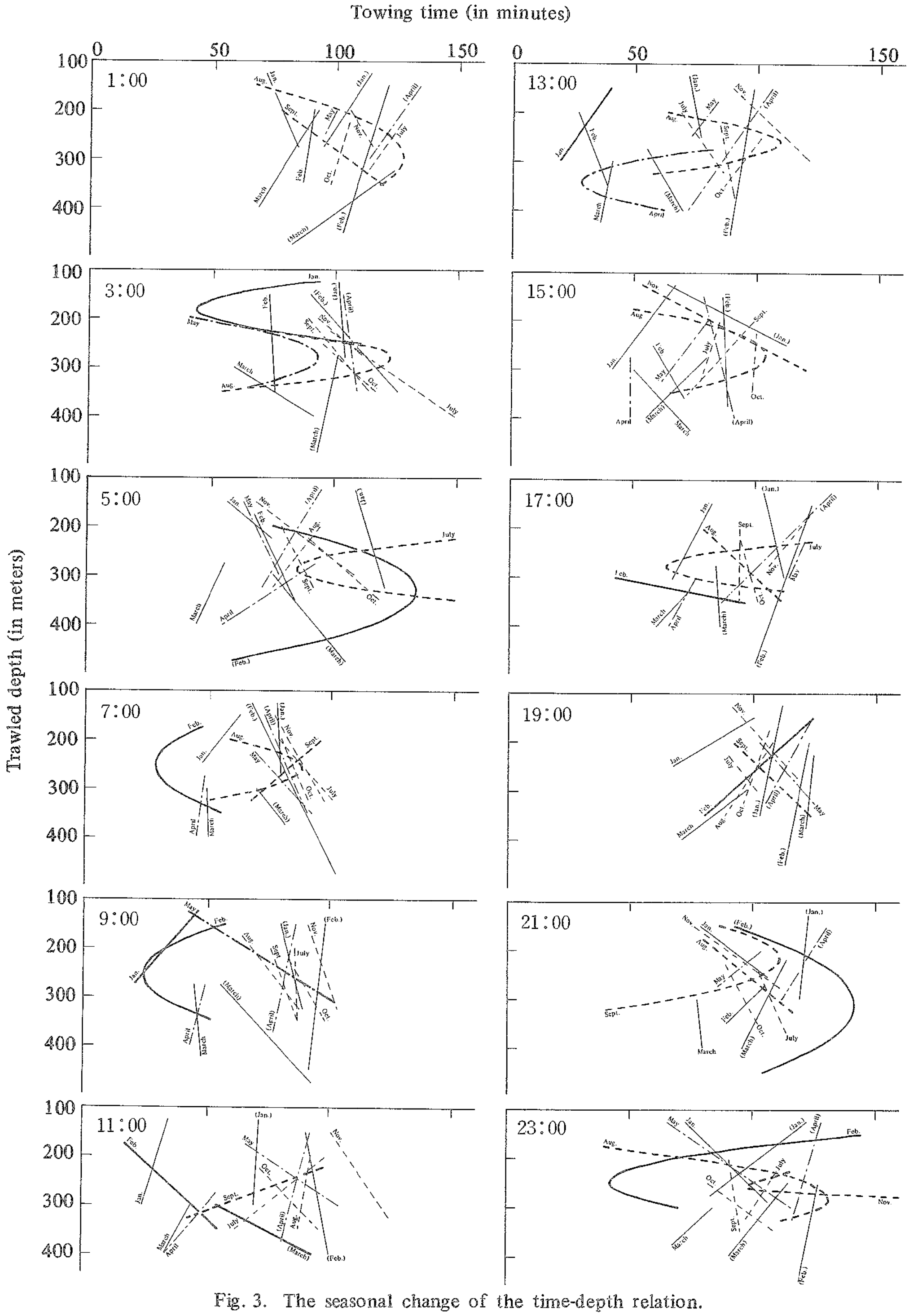

Fig. 3. The seasonal change of the time-depth relation.
Note : The month in parenthesis is in 1970.

regression lines in most of the months showed the shortening trend of towing time with depth. The towing time elongated from January to July. The regression lines for August and September showed the different trend from those of the other months. From Octover in 1969 to April in 1970, a rough trend of elongation with passing of season was suggested. And the elongation of towing time with passing of season was found between the lines for the same months in the different years. 3:00 ······ The towing time after July was long and showed an elongating trend with depth. 5:00 ····· Not only the coefficient but also the constant of the regression lines for the different months showed a severe and irregular change in accordance with passing of season. 7:00 ····· The lines for most of the months showed the similar trend of a slight elongation of towing time in accordance with depth and with passing of season. 9:00 ····· The towing time showed a slight elongation with depth and passing of season from July to November. 11:00 ····· The coefficient and constant of the lines showed a severe and irregular change. 13:00 ····· The coefficient showed a severe fluctuation; however, the towing time showed an elongating trend with passing of season from January to November, then showed a large monthly fluctuation. 15:00 ····· The difference of towing time in the first four months from those in the other months was smallest; the regression coefficient showed a large and irregular change; however, the towing time showed an elongating trend with passing of season from January to November. 17:00 ····· Not only the coefficient but also the constant of the regression lines showed severe and irregular change with passing of season. 19:00 ····· The towing time showed a shortening trend with depth in winter months and an elongating one in the other months, although this trend was rough and the seasonal change of towing time was small. 21:00 and 23:00 ····· Not only the coefficient but also the constant of the regression lines showed a large and irregular change; and it was hard to find any clear trends.

The results of this section were summarized, and the hour groups were classified according to the pattern of the seasonal change of the time-depth relation into as follows:

1) Shortening with depth in most of the months 1:00

2) Elongating with depth in most of the months 3:00 (after July), 7:00, and 9:00

3) Shortening with depth in the winter months and elongating with depth in the other months 19:00

4) Not only the coefficient but also the constant of the regression lines changed severely and irregularly with passing of season

5:00, 11:00, 13:00, 15:00, 17:00, 21:00, and 23:00

Discussion

The examinations in the first section revealed that the quadratic regression coefficient of the length of towing time on the trawled depth was positive in a half of the groups of the records of the towings in the same hours of the same months and was negative in the other half, although the coefficient was insignificant in most of the hour-month groups. The same was true to the linear regression coefficient. However, either the strata (the groups of records) taking the positive coefficient or those taking the negative one were distributed not by chance but their distribution had a relation to the month or showed the daily rhythmic change although its pattern differed monthly. The above mentioned results may be one of the representatives of the changes caused by the good use of the echo-sounder and other electronic supporting devices: the fishing ground was near steep sloaps along the outer edge of the continental shelf. The boat scouts the objective schools here and there along a zigzag course covering wide depth-range. And whether the detected school was attacked or not depends mainly on its probable size estimated through the echogram; and its detected depth is out of the problem so far as within the trawlable depth. Accordingly, the trawled depth fluctuated towing by towing. When the density of the objective fish shows a clear bathymetric difference, this may be found in the number of schools attacked, i.e. in the bathymetric change of the frequency of towings[1]. It is, however, hard to consider that the size of the attacked school, i.e. the length of towing time, shows a clear bathymetric difference, even when the distribution of the objective fish shows a clear bathymetric change.

The difference of the length of towing time due to daily rhythmic change was far larger than the difference due to bathymetric change. The clearest trend found in the comparison of the time-depth relation of the different hours in the same months was the daily rhythmic change — short towing in the daytime and long towing at night. And it is natural that a clear daily rhythmic change was found in the preceding report[3], in which the bathymetric difference was not taken into account. The clear daily rhythmic change may be due to the following reason: not only the behavior of the objective fish but also the work pattern of the crew, especially that of the hands working in the processing plant, show clear daily rhythmic changes. The boat fishes for the purpose of supplying the processing plant with material fish. In consequence, the fishing work depends on the daily rhythmic change of the behavior pattern of the objective fish and is modified by that of the capacity of the processing plant.

The daily rhythmic change of the length of towing time was far clearer than the bathymetric change of the length or the daily rhythmic change of the time-depth relation. One of the principal aims of the present report was, however, clarifying not the change due to the first two reasons but the difference due to the last one. In regard to the daily rhythmic change of the time-depth relation, the examination in the second section revealed the patterns differing monthly. This result may be due to the fact that the daily rhythmic difference was estimated stratifying the records of the consective towings into the strata according to the hour of shooting the net. Accordingly, it is natural that the estimated regression lines for the different hour groups in the same months showed a similar trend to one another or they showed somewhat regular change with passing of hour. And the different pattern of daily rhythmic change of the time-depth relation according to the months was because of the fact that the boat worked basing on the different backgrounds in many respects. The probable ones were seasonal bathymetric change of the distribution of the objective fish — the density, the distribution pattern (whether concentrated or scattering) and the behavior pattern (whether easily frightened with net or not) — in relation to the bathymetric difference of the extent of trawlable ground. The seasonal change of length of daytime may also be one of the representatives of the leading factors; however, the meaning of either the the daytime or night or dawn or dusk differs not only according to the length of daytime but also according as the boat is easily yielding sufficient material for the processing plant.

In regard to the seasonal change of the time-depth relation observable in the records of towings in the same hour, the clearest finding was the short towing in the first four months. This trend was clearer in the daytime than at night. The elongating trend of towing time in accordance with passing of season was found in many hour groups. These trends were found already in the preceding reports[1)-4)], in which the bathymetric difference was not taken into account, because of small bathymetric difference. The finding worth while giving much importance of the discussion was as follows: in spite of the fact that the time-depth relation showed a different pattern of daily rhythmic change monthly, the time-depth relations of different months in the same hour groups showed similar trends to one another in the Hour Groups 3:00, 7:00, and 9:00, when those in the earliest four months were excluded. The objective fish showed a seasonal bathymetric migration. The hours of the sunrise and the sunset show clear seasonal changes. It is probable to explain the severe monthly variation of the time-depth relations in the Hour Groups 5:00, 17:00, and 19:00 through the seasonal change of the hour of the sunrise and the sunset. It is, however, curious and hard to find the reason of the severe monthly variation in the Hour Groups 11:00, 13:00, and 15:00, when it is set that the work pattern of the boat depends on the probable daily rhythmic change of the behavior pattern of the objective fish and the behavior pattern of the objective fish primarily depends on the movement of the sun. Then, the reason may be as follows: the result of the present report was, in exact meaning, the change of the work pattern. The boat towed her net in short hours in the daytime and over many hours at night; in consequence, she conducted frequent towings in the daytime and less frequent one at night. The catch by a towing in the daytime was better than that at night. Accordingly, the major parts of the daily catch were yielded in the daytime, and it was hard to expect abundant supply of material fish at night. These facts make the skipper concentrate much attention to the fishing in the daytime. And the work pattern of the boat may be easily adapted to the conditions in the daytime, namely the work pattern was changed easily according to the conditions in the daytime. This fact resulted in a large variation of the time-depth relation of different months in the same hour groups of the daytime (11:00, 13:00, and 15:00). Such possibility as this was supported by a large variation of the length of towing time in these hour groups observable in Fig. 2 of the preceding report[3)] and the fact that the catch by a towing in the daytime showed slight decrease with passing of season while that at night decreased conspicuously.

The Hour Groups 1:00, 21:00, and 23:00 are at night throughout the seasons. The clearest difference of these hour groups from the above-mentioned ones was the lack of the records of short towings. The trend of short towing in the earliest four months was vaguest, the catch by a towing in these hour groups was poorest, and the towing time was longest. Namely, these hour groups were least profitable. The length of daytime shows a clear seasonal change. The amount of catch in the daytime or that of a day showed seasonal change, in spite of the fact that the daily capacity of the plant for processing the material fish is invariable regardless of the season. Accordingly, the necessity of catch at night differs seasonally — high in the season of poor catch but low in the season of good catch; and also the necessity of towing at night differs seasonally — low in the season of short night (summer) but high in the season of long night (winter); the daily rhythmic change of the behavior pattern differs not only according to the movement of the sun but also according to the seasonal change of the physiological conditions of the objective fish and the environmental ones. These facts suggested that the backgrounds of fishing at night differs seasonally. This may result in the variation of the work pattern in the hours of the least profitability.

In 3:00, 7:00, and 9:00, the time-depth relations of the records in the same hour in different months showed similar trends to one another, in spite of the facts that the objective fish showed a seasonal bathymetric migration and the hours of the sunrise and the sunset show clear seasonal changes. This result meant that, in the same hour over the ground of the same depth, the boat towed her net over the similar length of time regardless of the season. It is easily conceivable that the boat worked along a flexible pattern in the hours of high profitability (i.e. in the daytime) but along less flexible one in the hours of low profitability (i.e. at night). These hours showing small monthly difference in the time-depth relation were in the phase of the daily rhythmic change from the least profitable hour to the high one, covering the different hour of the sunrise according to the season. These hours were just before or after the beginning of the active work of the processing plant; and the carry over of the material fish during these hours was one of the most important bases of scheduling the day's work — determining the amount of fish for the reduced products and that for the minced ones. In this respect, the amount of catch during these hours was most important. All these facts suggested the possibility quitely contrary to the results obtained. And it was hard to find any fact supporting the results. However, the good similarity of the time-depth relations and the regular change of them in accordance with passing of hour (largely positive in 3:00 — slightly positive in 7:00 — negligibly positive in 9:00) made it difficult to regard that the present results were nothing but a chance coincidence.

Conclusion

The boat towed her net over many hours in some cases, while she towed only a short hour in the other cases, but the amount of catch by a towing did not differ according to the length of towing time. This fact seemed to suggest a possibility of the length of towing time applicable to show the difference in the density of the objective fish in the trawlable state. But the records used in the present series were collected from the commercial fishing; accordingly, they show the change of work pattern of the boat fishing for the purpose of supplying the material fish for the processing plant. This basic nature of the original records and the advance in the scouting techniques made it necessary to give consideration on the results paying much attention to the seasonal and daily rhythmic changes of the background of the records. And the results were explained as follows:

The boat scouts the schools along a zigzag course; and whether a detected school was attacked or not depends mainly on its probable size, and its detected depth was out of the problem. The work pattern like this made the bathymetric difference of the length of towing time not observable through the catch records, even when the density of the objective fish showed a clear bathymetric change. But it was hard to fill up the difference of the density of the fish in the trawlable state due to daily rhythmic change of the behavior pattern; and it is natural that the estimated regression lines of the length of towing time on the depth from the records of the different hours in the same months showed the similar trends to one another and showed somewhat regular change with passing of hour. The pattern of the seasonal change of the time-depth relations estimated from the records in the same hours differed hourly. The skipper concentrates his effort during the hours of high profitability; and it is natural that the time-depth relation in the daytime showed a severe seasonal change. The severe seasonal change of the time-depth relation at night may be due to the different necessity of fishing during the hours of the least profitability. In 3:00, 7:00, and 9:00, the time-depth relation of the same hours in the different months showed the similar trend to one another; it was hard to find any fact in support of this result, but not only the consideration from biological point of view but also from administrative point of view suggested the possibility contrary to the results obtained.

Summary

The preceding report revealed that the amount of catch by a towing did not differ in accordance with the length of towing time, in spite of the fact that the length of towing time fluctuated severely towing by towing. For the purpose of finding out the bathymetric difference of the density of the objective fish and its seasonal and daily rhythmic change, the catch records by a stern ramp factory trawler of about 4,000 gross tons during the season from Dec. '68 to April '70 along the outer edge of the continental shelf of the Eastern Bering Sea were stratified according to the hour of shooting the net, the month, and the ground; and the quadratic and linear regressions of the length of towing time on the trawled depth were estimated. And the following results were obtained:

1. The quadratic regression coefficient took the positive value in the 81 strata (the same hour in the same month on the same ground) of the records, including the significant

one in the eight strata; and the coefficient took the negative value in the same number of strata including the significant one in the 10 strata.

2. The linear regression coefficient took the positive value in the 86 strata including the significant one in the 10 strata; and the coefficient took the negative value in the 77 strata including the significant one in the five strata.

3. The difference of the length of towing time due to either the daily rhythmic change or the seasonal one was far larger than that due to the bathymetric change. This fact made it difficult to find the different trend of the bathymetric change either hourly or seasonally. It may be said, however, that the elongating trend of the towing time with depth inclined to be more frequently found in the morning or autumn and winter than in the other hours or seasons.

4. The records used in the present report were collected from the commercial fishing. In consequence, it was hard to neglect the possibility of the results modified by the administrative reason. And the above-mentioned results should be argued from the following point of view: the trend found in the present report did not show the seasonal — daily rhythmic — bathymetric change of the density of the objective fish in the trawlable state but showed the difference in the work pattern as the results of the interaction between the biological factors and the administrative ones.

References

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4) MAÉDA, H., 1974: *ibid.*, 23, 47–65.