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Title	STUDIES ON THE RELATIONSHIP BETWEEN CURRENT BOUNDARY ZONES IN WATERS TO THE SOUTHEAST OF HOKKAIDO AND MIGRATION OF THE SQUID, OMMASTREPHES SLOANI PACIFICUS (STEENSTRUP)
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STUDIES ON THE RELATIONSHIP BETWEEN CURRENT BOUNDARY ZONES IN WATERS TO THE SOUTHEAST OF HOKKAIDO AND MIGRATION OF THE SQUID, *OMMASTREPHES SLOANI PACIFICUS* (STEENSTRUP)

TSUNEYOSHI SUZUKI

Faculty of Fisheries, Hokkaido University, Hakodate, Japan

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I. Introduction

"Boundary zone" denotes the water area where different water masses come in contact, and convergence lines formed on the water surface induced by these water masses are defined as "current rips". Generally speaking, good fishing grounds are found around such a boundary zone, so current rip is searched for fishermen as an indication in seeking for the fishing grounds. Regarding the

study of boundary zones, various investigations have been made up to the present by many researchers from the viewpoints of oceanography and hydrobiology.

The writer has carried out a study on the relation between the migration of the squid, *Ommastrephes sloani pacificus* (Steenstrup), and the boundary zones in sea areas off southeastern Hokkaido, for the purpose of clarifying the effect of boundary zones upon the behavior of fishes and upon the formatoin of fishing grounds.

As for studies of squid, Kawana (1928, 1929, 1930, 1931, 1932 and 1934) and Isahaya (1928, 1930, 1931, 1932 and 1934) investigated the conditions for fishing of squid, hydrographic conditions and migration of squid. According to their investigations, in the case of good hauls, water temperatures at surface and mid-layer differ moderately, in the case of a usual haul they differ decidedly, while in the case of a poor haul or no catch they show the same temperature or only slight difference. As for the migration of squid, the above investigators have divided it into two types, northern type and southern one, both comprising a Pacific form and Japan Sea form. Miyamoto (1935) reported in his fishing experiments around Hakodate that the catch of squid is largest at 12°~24°C water temperature in areas shallower than 25 m in depth, and at 10°~18°C water temperature in water 40~60 m in depth. Sasaki (1921) observed that squid takes crustacea, squid (showing cannibalism) and small fishes as bait; he examined the gonad of squids caught on the coast from Kyushu to Hokkaido with reference to the fluctuation of fishing season of this species on the Japan Sea side. In this examination, though it was impossible to observe the creature's long migration from Kyushu to Hokkaido, he observed its densest shoals at 10°~17°C water temperature. Tauchi and Miyoshi (1940) surmised its migration, from its fishing conditions and irregularity of catches, to be formed of two shoals, viz. a long migration similar to that of *Sardinia melanosticta* (T. et S.), and a short local migration. Soeda (1946, 1947, 1948, 1949, 1950, 1951 and 1954) on the basis of recapture of tagged releases of squid in the Tsugaru Straits, discussed variation of water temperature around Japan, feeding habit of squid, fluctuation of its body length, and variation of fishing seasons; he stated that the squid around Japan makes a long migration from Saghalien to Kyushu, and that its fishing seasons coincide with the transition of surface water temperature 10°~17°C around Japan which gives optimum for squid. Takehana (1951 and 1955) stated, in view of data of vertical distribution of water temperature at Esan which faces the eastern entrance of the Tsugaru Straits and at Cape Shiriya during 1950 and 1954, that when the water masses below 10°C lie extremely low or oppressed towards the Esan area, haul is not good, whereas when the water

masses below 10°C appear near surface, haul is fine, being due to the change of population density owing in turn to the upward oppression or development of 10°~17°C water masses. In addition to these findings stated above, there have appeared various papers such as those by Yamamoto (1934 and 1946), Tanaka (1956), Nagata (1957) and Reports of the General survey on the Tsushima Warm Current (1958).

Uda (1930, 1936, 1938, 1943 and 1956), Kawai (1953), Kimura (1949), Matsudaira (1953), and the present writer (1959 and 1960) have also studied on the subject of boundary zones.

Concerning DSL (Deep Scattering Layer), a phantom bottom which appears on ultra sonic fish finder many papers have appeared; Hashimoto (1951, 1954, 1955, 1956 and 1957), Nishimura (1958), Uda (1952 and 1956), Kumagori and Suzuki (1958), Kampa (1956), Northrop (1953), Raitt (1948), Herdman (1953), Cushing (1956), Johanson (1953), Dietz (1948), Rose (1948), Bochus (1957), Borham (1957), Johnson (1956), Tucker (1951), Boden (1950, 1954 and 1956), Moore (1950), Maeda (1957) and Suzuki (1961) have studied four topics (A)~(D); (A) the physical causes such as discontinuous change of water temperature and change of density in DSL, (B) the biological causes owing to the dense masses of plankton, (C) relationship between DSL and light intensity, and (D) formation of fishing grounds.

Miyazaki (1952) studied the hydrographic conditions of waters to the southeast of Hokkaido and calculated the flow of the Tsugaru Warm Current to be ca. 3.8×10^{16} cm^3/day in February at minimum, and ca. 11×10^{16} cm^3/day in September to October at maximum. Sugiura (1955, 1957, 1958, 1959 and 1960) estimated the quantity of the Tsugaru Warm Current to be ca. 5×10^{16} m^3/sec. which is a value comparable to that of the Oyashio Cold Current, and that it moves to east at first from the eastern entrance of the Tsugaru Straits, turning to the south, southwest later, and finally it flows down the northeastern coast of Honshu as far south as 37°N. Yasui and Hata (1959) computed the transport of the Tsushima Warm Current to be $3\sim6\times10^6$ m^3/sec. and said that 70 per cent of it flows through the Tsugaru Straits, and then extends to southeastern sea area of Hokkaido.

Kawai (1955) presented a schematic hydrographic chart for the sea of Tohoku district being based on the observation data of hydrographic conditions in that sea area referring to observations by Suda (1936) and Uda (1938). According to Kawai (1955) polar fronts are composed of two strong streams, the Kuroshio Front and the Oyashio Front. By these two fronts the Tohoku sea area is divided into Kuroshio region, mixed region, and Oyashio region. Further-

more he touched upon the cut-off of solitary water masses formed by the division and offered some considerations from the point of view of hydrodynamics. Besides them, Koto and Suzuki (1949) and Hata (1953) have reported their observations in 'Kaiyo Sokuho' (Prompt Report) issued by the Hakodate Marine Observatory.

Squids caught between September and December in sea area off southern Hokkaido have been called autumnal squids. According to the authors listed above they migrate southward from the vicinity of Kushiro, and are divided off Cape Erimo into two shoals, one migrates toward the Sanriku Region, the other toward Esan. This division is considered to be influenced by various environmental factors, as no ecologically heterogeneous populations are found to exist among them. From 1954 to 1960, the present writer has analysed changes of hydrographic conditions off Cape Erimo, variation of food distribution of squids, and catches of squids off Sanriku and southern Hokkaido region, and endeavored to clarify the correlation between environmental factors and the division just mentioned.

Approximately 90 per cent of catches of squid are made by means of hand line fishing. The catches on the coast of Hokkaido attain ca. 50 per cent of total domestic catches of squids, and ca. 60 per cent of catches from Hokkaido are made in the region off southern Hokkaido. The amounts of catches of squids in this region directly and greatly influence the economic situation of shore fishermen who get livelihood from squids. Therefore the writer considers the studies on squids most significant; according by he has initiated the present studies.

Before going further, the writer would express gratitude to Prof. T. Kawakami, Faculty of Agriculture, Kyoto University for his cordial guidance in this studies and revising this manuscript. He also is deeply grateful to Prof. S. Motoda, Faculty of Fisheries, Hokkaido University for guidance on the ecology and identifications of planktons, to Prof. M. Kanamori, Prof. T. Kuroki, and Asst. Prof. K. Kyushin for their invaluable suggestions on the fishing grounds and hydrographic conditions, to Instructor Y. Akiba of the same university, and Mr. K. Hata of the Hakodate Marine Observatory for various items of information on fishing conditions. Furthermore he is grateful to Prof. E. Tanikawa and Asst. Prof. H. Ohmi, Faculty of Fisheries, Hokkaido University for constant interest in this study, to Dr. J. Soeda, ex-Director of the Hakodate Branch, Hokkaido Regional Fisheries Research Laboratory, to ex-Messrs. T. Takayama and T. Asai of the Hakodate Statistics and Survey Office, Ministry of Agriculture and Forestry, to Mr. M. Nakamori, Fisheries Agency of the same Ministry for their kind help in the collection of samples, and to ex-Messrs. H. Tsujizaki, K.

Sakamoto and K. Nakamichi of Hokkaido Fisheries Scientific Institution, members of the crews of the Tankai Maru, and the Oyashio Maru, many students of Navigational Instruments, Faculty of Fisheries, Hokkaido University for their co-operation in the study, and finally to the Military Air Base, Northern District who allowed the writer to board a plane for survey.

II. Materials and Method Employed

2. 1. Source of materials

Data on catches of squids were based on Agriculture, Forestry and Fishing statistics monthly (1952~1960) and annual report of catch statistics on fishery and agriculture (1952~1959) issued by Statistics and Survey Division, Ministry of Agriculture and Forestry. Numbers of monthly fishing trips classified by type of fishery were based on the interim tabulations (1954~1960) by Statistics and Survery Offices, Ministry of Agriculture and Forestry at Kitami, Obihiro, Hakodate, Aomori, Iwate and Miyagi.

Data on occeanographical observations were based on 'Kaiyo Sokuho' or prompt Report (1952~1960) issued by Hakodate Marine Observatory, and the Results of Marine Meteorological and Oceanographical Observations (1952~1960) issued by the Meteorological Agency. In addition to the above, use was made of information gained by the writer himself on board the research boats 'Tankai Maru' of the Hokkaido Regional Fisheries Research Laboratory, and 'Oyashio Maru' of the Hokkaido Fisheries Scientific Institution during the year 1960 and 1961.

For the search of DSL a Sanken Co. Ltd. ultra sonic fish finder was used, equipped with 200 KC frequency, 150/min. ultra sonic pulses in shallow waters, 75/min. pulses in deep waters, 7.6° in beam angle (half power angle), with attached CRT and wet paper system.

Plankton samples were collected vertically in 1960 by means of a closed net, 30 cm in caliber and 95 cm in length, and by a north Pacific standard net, 45 cm in caliber and 180 cm in length, both made of domestic silk GG 54, at 4~5 m/sec. towing velocity. In horizontal collections of plankton samples, a north Pacific standard net was towed for an hour at various depths from the water surface. When DSL was seen in water surface, a net for larval fishes, 130 cm in caliber and 450 cm in length, was towed for 10 minutes at water surface at ca. 2 knots. Light intensity in the air and water was measured by a bathyphotometer with Seren photo-cells, of which the capacity is $0.7 \sim 10^5$ lux.

2. 2. Treating of data

2. 2. 1. Ship performance and estimated total fishing efforts

Various sizes are seen in boats engaged in hand line squid fishing. They are categorized statistically into eight grades: non-powered boat, powered boat of tonnage 0~3, 3~5, 5~10, 10~20, 20~30, 30~50 and 50~100. As the number of anglers on board a single boat and the number of fishhooks per angler vary, catching rate is shown by the following equation. When q denotes catchability coefficient, and X denotes a fishing effort, total estimated fishing effort is given in

$$\tilde{X}_0 = X_0 + \frac{q_1}{q_0} X_1 + \frac{q_2}{q_0} X_2 + \cdots\cdots \quad (1)$$

In this equation, q_0 indicates a fishing coefficient of a fishing gear installed in a standard boat, and X_0 indicates a fising effort of that boat. Boats belonging to the grade of 10~20 tons are treated as standard, as they catch most. Total estimated fishing effort is implied as a factor of total number of trips. As catchability coefficient use was made of average number of fishhooks which are employed on boats of various grades. Average number of anglers on board a boat and average number of fishhooks per angler are shown in Table 1, being based on the data procured from Hakodate Branch of Hokkaido Fisheries Scientific Institution, Hakodate Office of Statistics and Survey Division, Ministry of Agriculture and Forestry, various dealers of fishing tackle in Hakodate, Fishery Division of Hachinoe City Office, Hachinoe Fisheries Co-operative Association, and two shipowners each in Hakodate and Hachinoe.

Table 1. Relationship between ship performance and catchability coefficient

Grade of size		Average number of fishermen	Average number of fishhook per a fisherman	Catchability coefficient
Non powered		2	8	0.01
Powered,	0~ 3t	3	10	0.05
〃	3~ 5	6	35	0.33
〃	5~ 10	10	35	0.52
〃	10~ 20	18	35	1.00
〃	20~ 30	20	35	1.11
〃	30~ 50	23	35	1.28
〃	50~100	30	35	1.67

2. 2. 2. Effective fishing efforts and index of population abundance

The following relation is seen between actual fishing effort and effective effort $\bar{X}$. Total area A of fishing ground is divided into $i(=1, 2, \ldots)$, and total

catch C is also divided into i.

$$\frac{CA}{\bar{X}}=\sum_i \frac{C_iA_i}{X_i} \tag{2}$$

when $X=\sum X_i$

$C=\sum C_i$

$A=\sum A_i$

$$N'=\sum \frac{A_iC_i}{X_i} \tag{3}$$

$$C=\frac{\bar{X}}{A}N'$$

This N' is called index of population abundance.

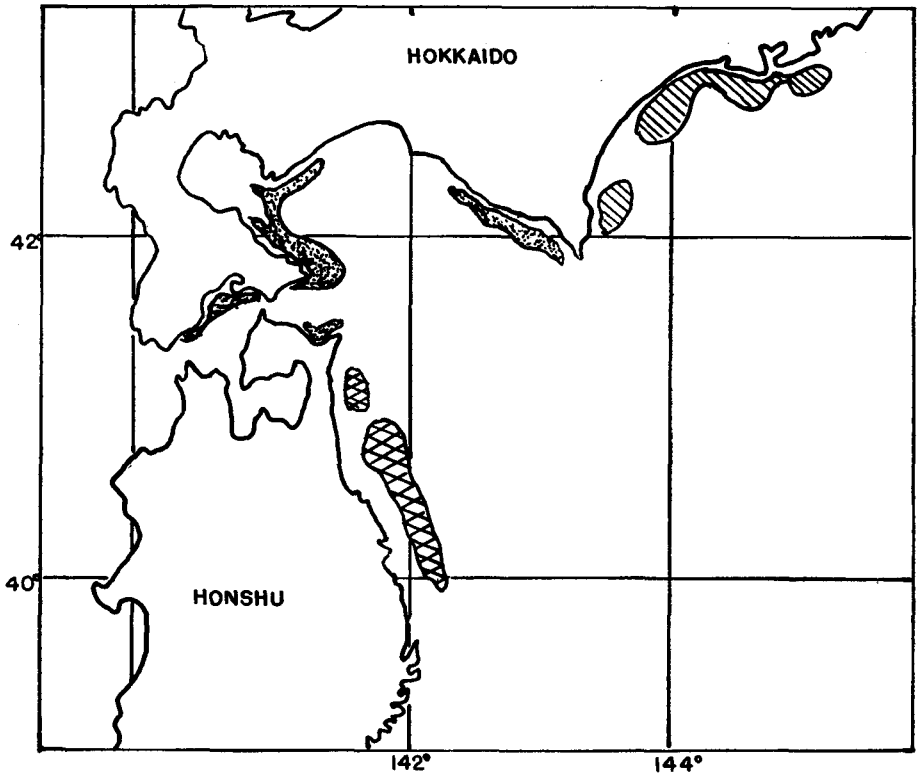


Fig. 1. A chart showing the general locations of squid fishing grounds in the waters of eastern and southern Hokkaido and Sanriku district

As for area of fishing grounds the following data were procured being based on telegrams on fishing conditions supplied by Hakodate Branch, Hokkaido Fisheries Scientific Institution, and various items of news from Hakodate Office, Statistics and Survey Division, Ministry of Agriculture and Forestry, Fishery Division, Hachinoe City Office, Hachinoe Fisheries Co-operative Association.

Kushiro and Tokachi Region	2.332.250 km^2
Southern Hokkaido Region	2.085.980 km^2
Sanriku Region	2.501.600 km^2

The locations of fishing grounds from August to November in Kushiro and Tokachi Region, and from September to December in southern Hokkaido and Hachinoe Region are shown in Fig. 1.

2. 2. 3. Reflection loss of ultra sonic wave (db)

When intensity of reflective sound wave is treated, its reflection loss should be taken into consideration. Reflection loss indicates the ratio of incident sound pressure (P) upon reflective bodies to sound pressure (P_d) which reflects back toward the sound source in unit distance (m in length).

When the ratio $P : P_d = r$,

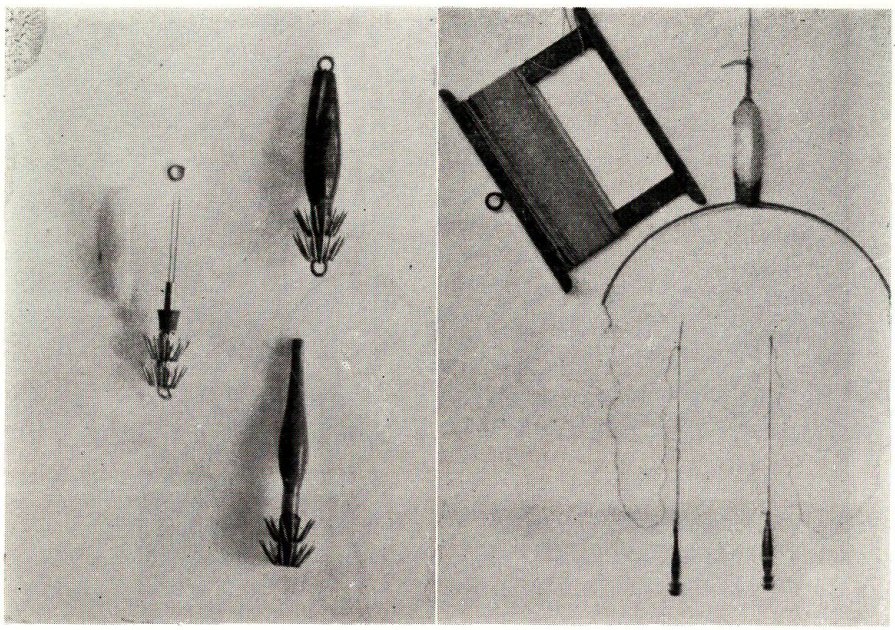
$$\text{Reflection loss} = 20 \log_{10} |r| = -20 \log_{10} \left| \frac{1}{r} \right| \qquad (4)$$

III. Fishing Tackles and Fishing Method for Squid

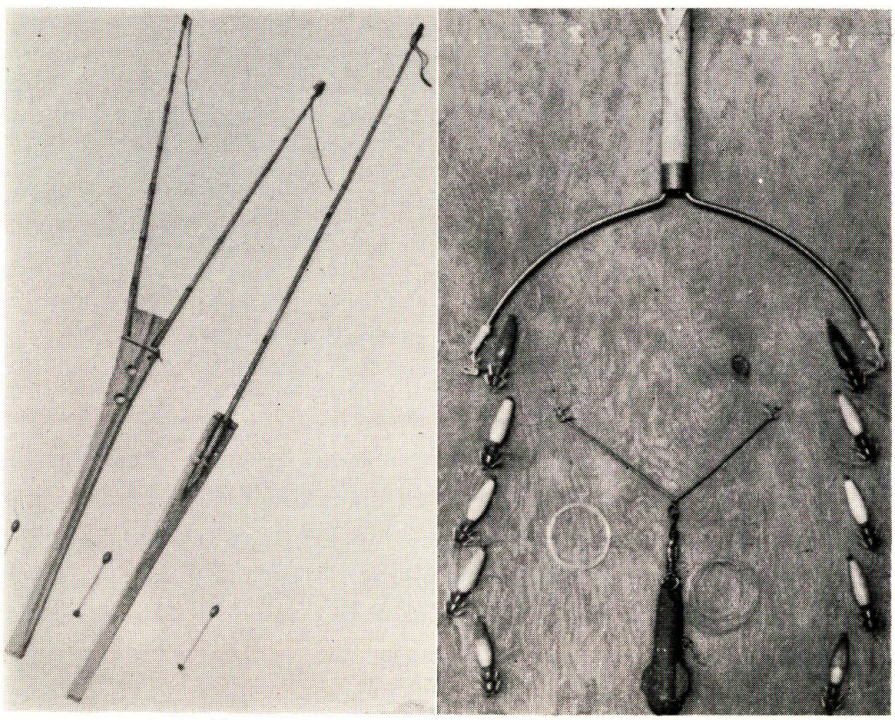
Fishing tackles for squid such as "Tombo", "Sokomata", and "Hanego" have scarcely been improved since the Meiji era up to the present. Poles of "Tombo" "Sokomata" are made of lead, iron, or crockery acting as sinker, ca. 15 cm in length, and ca. 4 cm in diameter. As shown in Fig. 2, b. two curved brass hands, ca. 20 cm in length, 0.5 mm in diam., expand downward at 80°. To their top a gut (ca. 50 cm in length) is attached together with a hook. To the stalk a fishing line (30~50 m in length) is attached, which is called "Sekiyama", or "gang leader". These two fishing tackles, "Tombo" and "Sokomata", are used to fish for squids in mid-water layer by line fishing.

"Hanego" is a bamboo pole fishing tackle, shown in Fig. 2, c. 50~60 cm in length, and is used to fish squids near surface. There are two kinds of "Hanego", a single pole fishing tackle, and two poles fishing tackle. To the top of poles, a gut (ca. 50 cm in length) is attached together with a hook.

Upon arriving at a fishing grounds, fishermen cast "Tombo" and "Sokomata" into the water spreading and controlling fishing lines up and down by a hand, and thus set many hooks be at various depths. Once the length of a gut is settled,

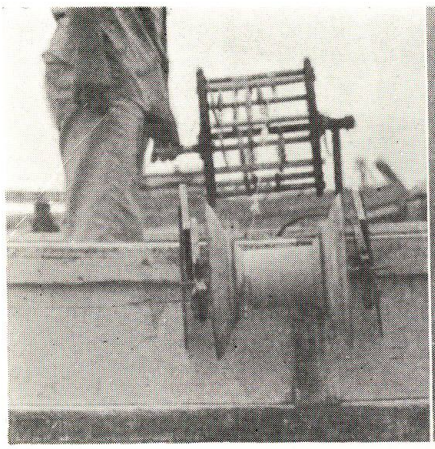


(a) (b)

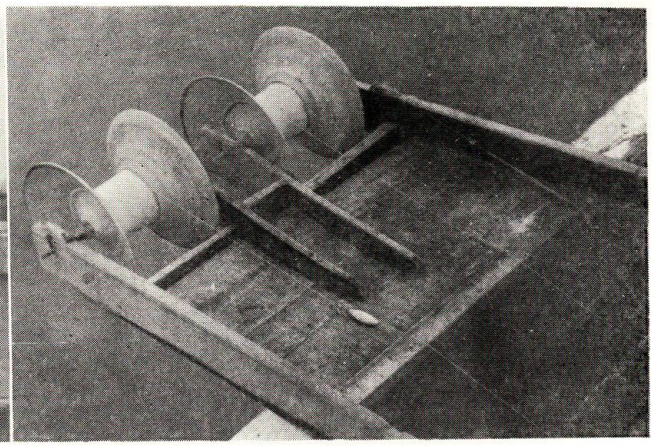


(c) (d)

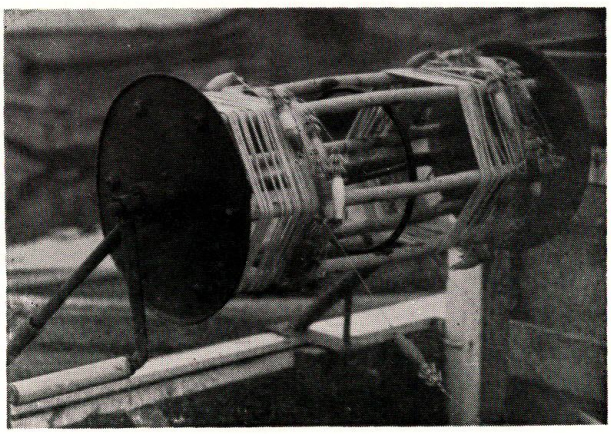
Fig. 2 (a–d). Fishing tackles for squid.
(a) "*Fish-hook*", (b) "*Tombo*" or "*Sokomata*", (c) "*Hanego*", (d) "*Suzuran Tsuri*"



(e-1)



(e-2)



(e-3)

Fig. 2 (e). Fishing tackles for squid.
(e) "*Zororí*" ("*Wappa* and *Drum*" e-1-Single. e-2, 3-Double) also called "*Mambo*".

vertical vibration or up and down movements are continuously given by the fishermen; when squids are hooked they are hauled instantly; these operations are many times repeated. The length of all the fishing lines is at once adjusted to the depth of water at which squids are secured first, and at this depth fishing lines are moved vertically by a fishermen's hand. When many squids begin to be caught, fishing lines are shortened gradually to lead squid shoal to shallower water. Thus when they are seen in the upper water, "Hanego' 'is used in place of "Tombo" and "Sokomata".

On the other hand, since World War II, 2~5 hooks have been attached in place of a single hook to hand of "Tombo" which is name from the use of a cluster

of hooks i.e. "Suzuran-tsuri" (fishing hooks look like flowers of lily of the valley. See Fig. 2, d). At about the same time Asari's fishing system, devised by Mr. Asari in Hachinoe appeared; it uses two brass handles on a wooden pole. To each of two handles, five hooks are attached vertically, and a gut with a leaden sinker is fixed to the lowermost hook. The connected fishing system or "Suzuran-tsuri" and Asari's system mentioned above were employed until 1950 or so. Since about 1951 "Zorori" system (Fig. 2, e) has become prevalent rapidly as it proved most effective for fishing squids along the coast of Matsumae, southern Hokkaido. In this system, 30~40 hooks are attached at ca. 50 cm intervals to a nylon line, to the end of which is fixed a sinker. A roller or "Wappa" is installed on the ship's side in this system. When hauling fishing lines by hand, they are coiled on the two hands of fishermen; this system of fishing is called "Mambo" as fishing lines look like Mambo-dancing then hauled. Formerly they were coiled on both hands as stated above, but after about 1955 they have been coiled on a drum, as fishermen are apt to get very tired when coiling fishing lines on their hands, so this system may be called to give it another name "single line fishing with drum" (see Fig. 2, e).

IV. Results

4. 1. General aspects of squid fishing

As known from Table 2, catches of squid in Japan comprise ca. 90% of the total catches of squids and cuttle fishes in Japan which are shown in Fig. 3, being increased by powered fishing boats since about 1920, and by extension of fishing grounds from coastal waters to the open sea. Especially since World War II, fishing boats have increased in number, and fishing gears for squid have been improved causing rapid increase of squid catches to a record 6×10^5 tons in 1952. Since that year squid catches have gradually decreased showing 3×10^5 tons in 1956, later again increased to 4×10^5 tons.

In recent years, as shown in Table 3, squid have attained to 6~14% of total annual yield of marine products excepting that of whale fishery in Japan, thus forming one of the important resources in the coastal fisheries in Japan.

Above all, the squid catch from Hokkaido has attained to ca. 50% of the total from all Japan. Especially the catch is large in southern waters og Hokkaido, showing over 60% of that from all Hokkaido (cf. Tables 4, 5 and Fig. 4). However, since 1956 annual squid catches from southern waters of Hokkaido have fluctuated greatly exhibiting an unstable condition (Tables 4, 5 and Fig. 4).

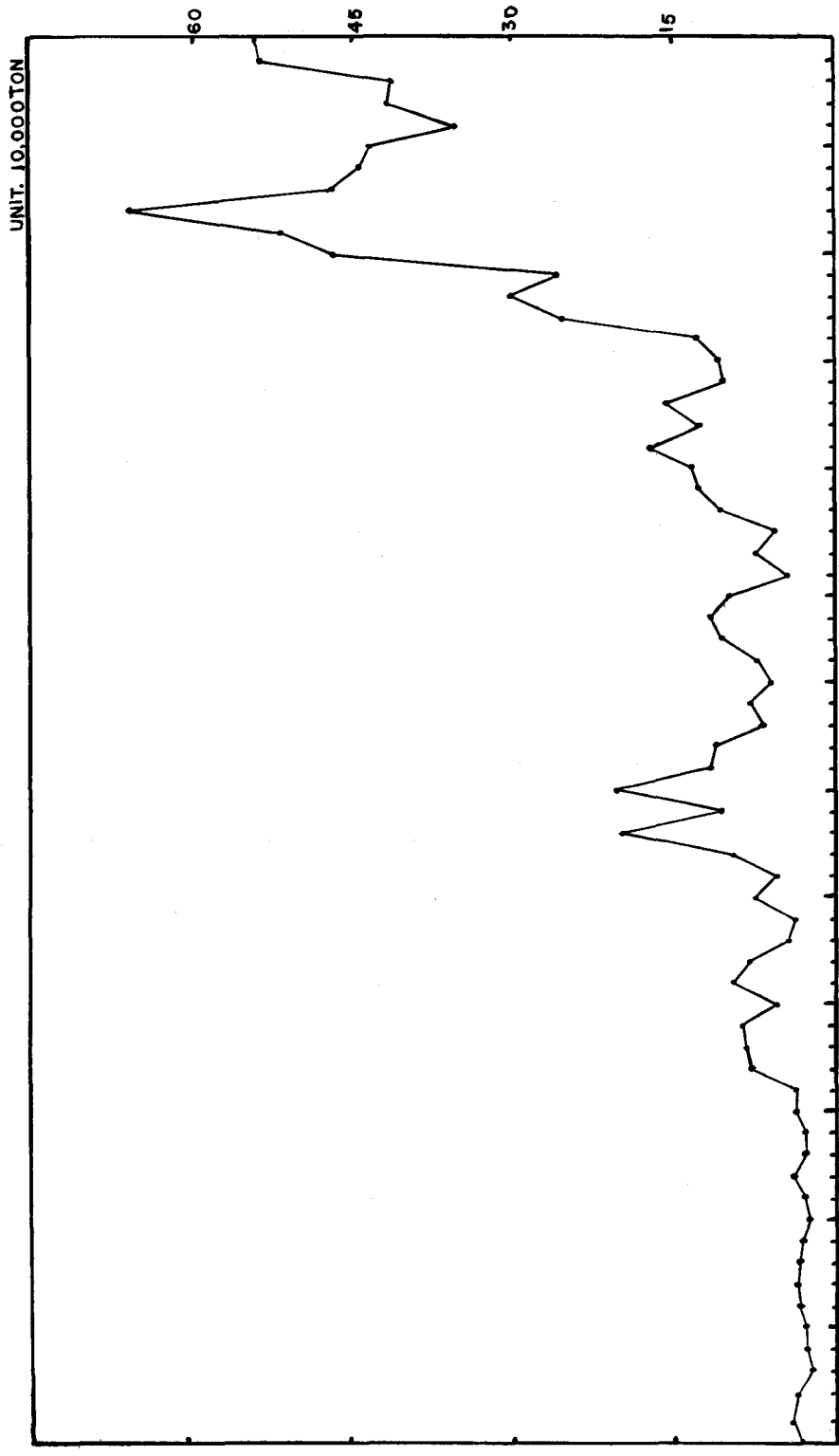


Fig. 3. Annual trend of total squid catches and cuttle fish in 1895–1960

Table 2. Comparison of catches of cuttle-fish and squid

(unit ten thousand tons)

Year	Cuttle fish and squid	Squid	Ratio (%)
1952	65.6	60.0	91.5
1953	46.8	42.0	89.7
1954	44.3	40.0	90.3
1955	43.4	38.0	87.6
1956	35.4	30.0	84.7
1957	41.8	36.4	87.1
1958	41.2	35.0	85.0
1959	53.8	48.0	89.0
1960	54.2	48.0	88.6

Furthermore, approximately 90% of squid catches are made by means of line fishing (Table 5), a most primitive method, but it forms an important fishery for poor fishermen. Consequently the amount of squid catches exert great influence upon the economy of those fishermen.

Taking the fact into consideration that squid catches from eastern waters of Hokkaido (Provinces Kushiro and Tokachi), southern waters of Hokkaido (Provinces Hidaka, Iburi and Oshima), and the Sanriku coast such as Aomori and Iwate Prefecture attain to ca. 70% of those from all Japan (cf. Tables 4, 5), the writer has analysed the correlation between squid catches and hydrographic conditions in the waters of southern Hokkaido and the Sanriku district following 1952.

Soeda (1950) divides squids caught in southern Hokkaido waters into two

Table 3. Comparison of total yield of all fisheries excluding that of whale fishery with squid catch in Japan

(unit ten thousand tons)

Year	Total yield of all fisheries	Squid catch	Ratio (%)
1952	446.3	60.0	13.4
1953	452.5	42.0	9.3
1954	454.5	40.0	8.8
1955	491.3	38.0	7.7
1956	477.0	30.0	6.3
1957	539.9	36.4	6.7
1958	550.0	35.0	6.4
1959	588.0	48.0	8.2
1960	514.0	48.0	9.3

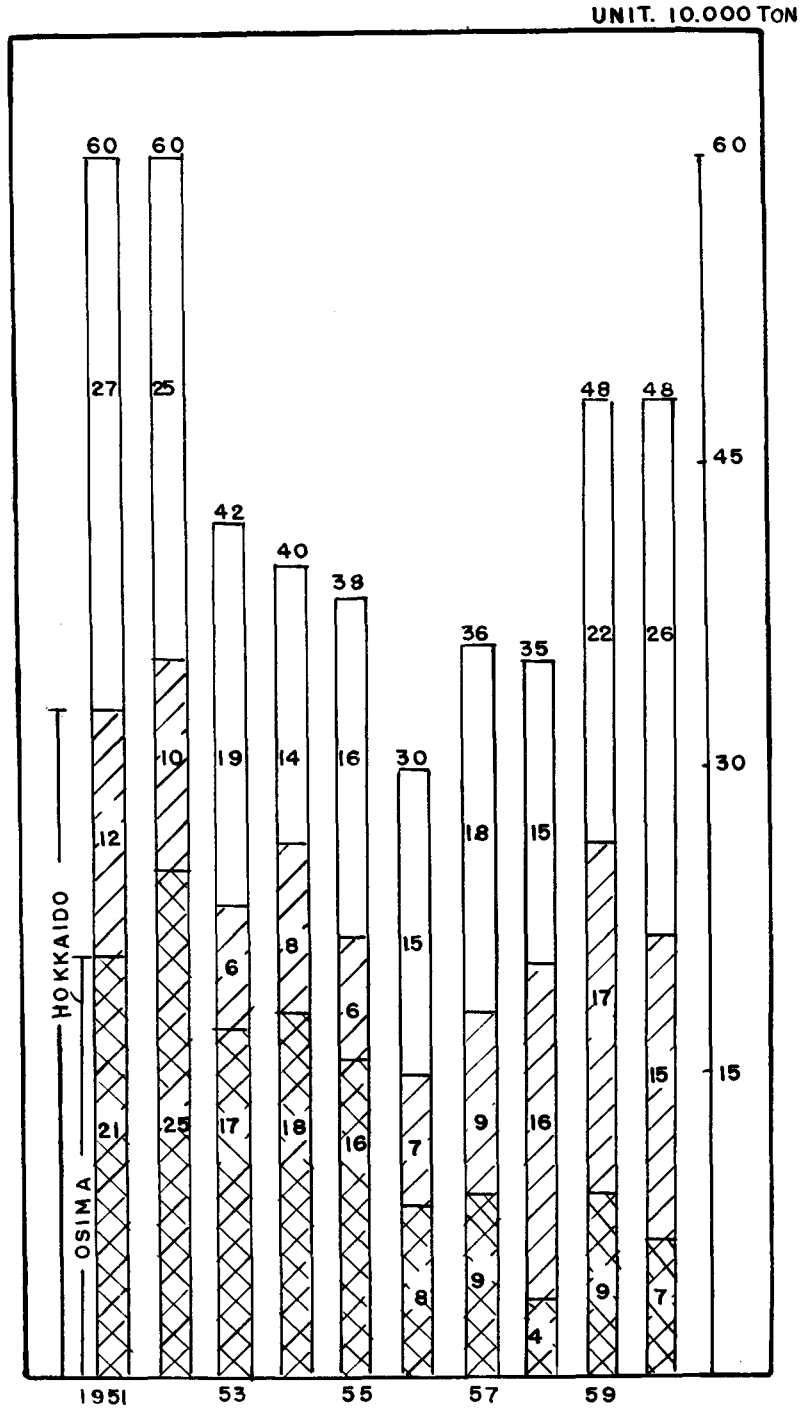


Fig. 4. Sequent fluctuation of the annual catches of squid in Japan, Hokkaido and Oshima province in 1951–1960. ▨—Total catches in Oshima province, ▨—Total catches in Hokkaido, ▭—Total catches in Japan

Table 4. Total annual squid catches in Japan

(unit in tons)

Year	Amount of catches and ratio of local catches to total catches in Japan	Localities where squids were caught						
		All Japan	Hokkaido	Prov. Oshima, Iburi, Hidaka, Tokachi, Kushiro and Aomori pref.	Prov. Oshima	Aomori pref.	Iwate pref.	Prov. Nemuro
1952	Catches	600,870.00	347,490.00	438,588.75	258,037.50	117,011.25	32,257.50	2,088.75
	Ratio (%)		57.83	72.99	42.94	19.47	5.39	4.38
1953	Catches	420,086.25	229,683.75	436,365.00	160,080.00	97,451.25	37,620.00	783.75
	Ratio (%)		54.68	82.45	38.11	23.20	9.00	0.19
1954	Catches	398,745.00	259,301.25	305,632.50	172,207.50	82,548.75	11,550.00	1,252.50
	Ratio (%)		65.03	76.65	43.19	20.70	2.90	3.14
1955	Catches	383,418.75	221,336.25	315,697.50	191,516.25	92,017.50	29,688.75	2,475.00
	Ratio (%)		57.73	82.34	49.95	24.00	7.74	0.75
1956	Catches	299,486.25	149,092.50	238,965.00	78,472.50	97,181.25	22,740.00	20,996.25
	Ratio (%)		48.88	79.79	26.20	32.45	7.59	7.01
1957	Catches	364,365.00	175,113.75	262,117.50	89,947.50	101,748.75	20,336.25	18,022.50
	Ratio (%)		48.06	71.94	24.69	27.92	5.58	4.95
1958	Catches	354,225.00	193,332.00	250,200.00	95,494.00	85,537.00	15,649.00	45,355.00
	Racio (%)		54.58	70.63	26.96	24.15	4.42	12.80
1959	Catches	480,667.00	257,971.00	363,294.00	39,908.00	129,825.00	28,675.00	59,365.00
	Ratio (%)		53,67	75.58	8.30	27.01	5.97	12.35
1960	Catches	480,661.00	255,854.00	353,484.00	73,766.00	116,965.00	21,096.00	64,711.00
	Ratio (%)		53.23	73.54	15.35	24.33	4.39	13.46

Table 5. Total annual catches of squid by means of line fishing

(unit in tons)

Year	Annual of catches and ratio of local catches to total catches in Japan	Localities where squids were caught						
		All Japan	Hokkaido	Prov. Oshima, Iburi, Hidaka, Tokachi, Kushiro and Aomori, Iwate Pref.	Prov. Oshima	Aomori pref.	Iwate pref.	Prov. Nemuro
1952	Catches	576,026.25	333,015.00	414,997.50	245,782.50	115,567.50	27,573.75	791.25
	Ratio (%)	94.37*	57.83	73.19	43.35	20.38	4.86	0.14
1953	Catches	406,083.75	221,760.00	331,672.50	151,653.75	97,113.75	30,570.00	251.25
	Ratio (%)	96.67*	54.61	81.68	37.35	23.91	7.53	0.06
1954	Catches	383,351.25	249,018.75	292,233.75	163,530.00	83,685.00	8,711.25	1,035.00
	Ratio (%)	96.14*	64.96	76.23	42.65	21,83	22.72	0.27
1955	Catches	374,355.00	215,557.50	306,753.75	157,162.50	91,125.00	26,790.00	1,702.50
	Ratio (%)	97.64*	57.58	81.94	41.98	24.34	7.16	0.45
1956	Catches	274,158.75	125,670.00	213,198.75	67,533.75	96,506.25	19,672.50	9,997.50
	Ratio (%)	91.54*	45.84	77.76	24.63	35.20	7.18	3.65
1957	Catches	352,518.17	166,912.50	252,108.75	84,408.75	101,238.75	17,013.75	12,621.25
	Ratio (%)	96.75*	47.35	71.52	23.94	28.72	4.82	5.00
1958	Catches	352,658.00	188,870.00	245,378.00	37,272.00	85,171.00	14,189.00	45,115.00
	Ratio (%)	99.56*	53.56	69.58	10.57	24.15	4.02	12.79
1959	Catches	470,282.00	247,869.00	351,879.00	90,652.00	128,210.00	25,853.00	59,382.00
	Ratio (%)	97.84*	50.58	74.82	19.28	27.26	5.50	12.50
1960	Catches	469,918.00	245,514.00	207,896.00	69,963.00	115,775.00	19,429.00	41,566.00
	Ratio (%)	97,96*	52.24	44.24	14.19	24.64	4.13	8.85

* Asterisk indicates ratios of total squid catches from all Japan to those by means of a live fishing.

populations, one migrating northward, and the other southward, but he presumes those two have the same origin. According to him, squids which have migrated northward in the Japan Sea and the Pacific Ocean are caught in these waters as summer squids in June~August. They migrate as far east as Kushiro and Nemuro, and as far north as Saghalien. They shortly make the reverse migration southward, and are caught in the same waters as autumnal squids in September~December. He presumes that squids which migrate southward from the Kushiro coast migrate westward clockwise past Cape Erimo and reach the waters near Esan. They separate there into two, one migrating westward into the Tsugaru Strait, the other migrating southward along the Sanriku coast. On the basis of tagging release experiments of squids made near Esan at that time, he seems to have reached the above conclusions.

Tagging release experiments of squids made by Hokkaido Regional Fisheries Research Laboratory and Hokkaido Fisheries Scientific Institution off Hanasaki and Kushiro since after 1954 have led to the conclusion from the result of recapture of released squid, that squids which migrated southward from Kushiro coast separate into two branches near Cape Erimo, one migrating toward Esan,

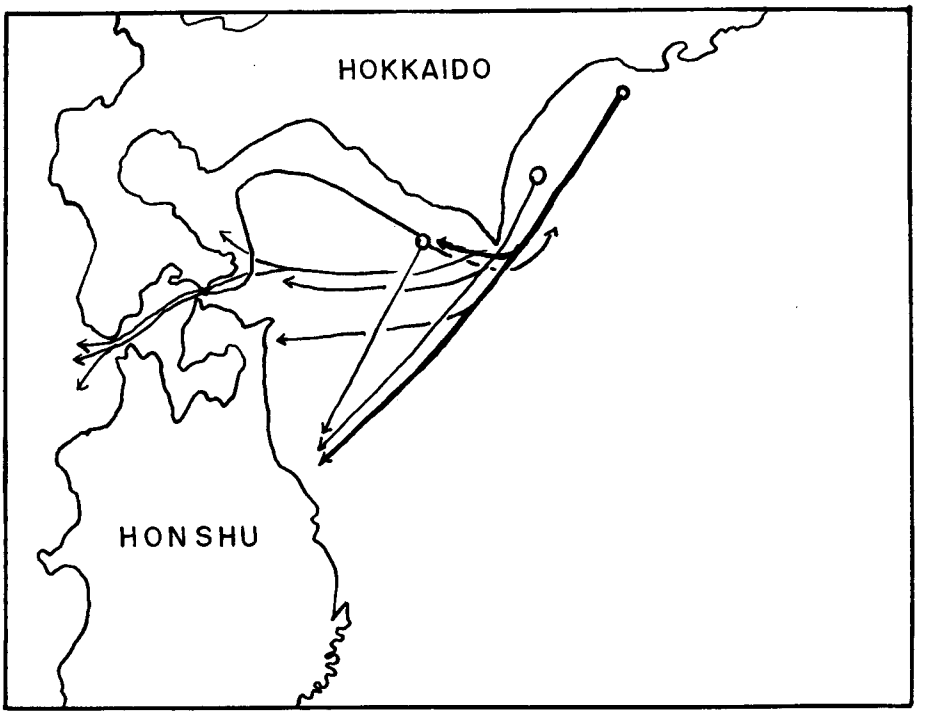


Fig. 5. Results of the tagging release experiments of squids in 1953-1957

and the other toward Sanriku coast (Fig. 5). Some investigators consider this separation to be due to ecological, and others that it is due to the limiting factors of hydrographic conditions. Concerning the former consideration, morphological and ecological studies of squids were made, but no heterogeneous populations were formed among them. Therefore the latter consideration is now prevailing. (cf. Progress report of the cooperative investigations of important neritic-pelagic fisheries resources, 1956~1957, and reports of the general survey of Tsushima Warm Current, 1958).

The writer agrees with the latter consideration of the basis of facts that fishing grounds of autumnal squids move from eastern Hokkaido seas to southern Hokkaido seas with the changes of fishing seasons (from August to September, October and November), and that major fishing seasons of squids are in October and November both in southern Hokkaido waters and in Sanriku waters. He has investigated the relationship between behavior of squids migrating southward and environmental factors of the waters in which they live.

Squids are commonly caught at present in considerably shallow waters. As for off shore waters, hydrographic conditions remain unknown, and the stock of squids in the open sea is also unknown. Therefore the following statements are only concerned with the comparison of relative population density of squids to be caught in the present fishing grounds under present hydrographic conditions.

Data used are those after 1954, as those before 1953 are not available. Fishing date such as number of fishing boats, equipment of fishing boats, and number of trips have been greatly improved since 1957. This improvement was made after the poor catch of squids in 1956 caused by the removal of fishing ground from southern Hokkaido waters to waters in eastern Hokkaido and Sanriku district.

To get the value of fishing effort, total estimated number of trips $\tilde{X}_0$ in each water was calculated from formula (1). Relative value of fish stock to be caught was indicated as catch per unit effort (CPUE) in each water, being calculated from $\frac{C_i}{\tilde{X}_0}$ per unit trip during the fishing season of squids which had migrated southward.

Inasmuch as squid shoal is separated into two branches, one migrating toward southern Hokkaido, and the other toward the Sanriku coast, catch statistics of squids in each water was combined as follows:

Eastern Hokkaido sea — Catches in Provinces Kushiro and Tokachi.

Southern Hokkaido sea — Catches in Provinces Hidaka, Iburi, Oshima, and the coast facing the Tsugaru Straits, Aomori prefecture, eliminating

catches in the Japan Sea of Oshima Province.

Sanriku sea — Catches in Aomori prefecture (excluding the Tsugaru Straits) and Iwate prefecture.

Catches from Ohata and Mutsu Bay are made in waters around Esan, Shiriya and the Tsugaru Straits, so they are treated as belonging to the branch migrating toward southern Hokkaido. Catches from Matsumae, Kojima, and Era in Oshima

Table 6. Annual autumnal catches of squids by line fishing since 1954 in the waters of eastern and southern Hokkaido, and Sanriku district, number of trips(N), estimated numbers of trips($\tilde{X}_0$), and CPUE

Year	Items	Eastern Hokkaido seas	Southern Hokkaido seas	Sanriku seas	Total
1954	Catches (tons)	25,627.50	119,399.20	36,925.97	181,892.67
	Number of trips (times)	8,057	67,241	44,555	119,853
	$\tilde{X}_0$ (times)	5,890.82	41,807.00	33,350.32	81,048.14
	CPUE (tons)	4.35	2.85	1.11	8.31
1955	Catches (tons)	22,152.50	126,897.89	69,654.63	149,050.47
	Number of trips (times)	4,726	51,812	62,094	118,632
	$\tilde{X}_0$ (times)	3,863.90	36,731.39	32,750.94	73,346.23
	CPUE (tons)	5.73	3.45	2.13	11.31
1956	Catches (tons)	11,056.25	49,917.13	68,002.51	128,975.94
	Number of trips (times)	3,692	52,186	55,394	111,272
	$\tilde{X}_0$ (times)	2,986.16	39,859.40	29,715.63	72,561.19
	CPUE (tons)	3.70	1.25	2.29	7.24
1957	Catches (tons)	24,116.25	63,840.12	70,983.82	158,940.19
	Number of trips (times)	6,983	61,951	54,802	123,736
	$\tilde{X}_0$ (times)	5,765.03	36,811.41	43,783.81	86,360.25
	CPUE (tons)	4.18	1.73	1.62	7.53
1958	Catches (tons)	32,126.00	31,107.49	76,099.98	139,333.47
	Number of trips (times)	8,516	41,519	55,308	105.343
	$\tilde{X}_0$ (times)	8,292.62	27.186.72	40,610.23	76,089.57
	CPUE (tons)	3.87	1.14	1.87	6.88
1959	Catches (tons)	41,203.00	59.361.43	71,992.10	172,556.53
	Number of trips (times)	8,758	52,083	63,325	123,166
	$\tilde{X}_0$ (times)	8,085.29	26,924.26	45,419.02	80,428.57
	CPUE (tons)	5,09	2.20	1.58	8.87
1960	Catches (tons)	71,425.00	45,886.20	60,296.35	177,607.55
	Number of trips (times)	12,108	53,495	50,598	116,201
	$\tilde{X}_0$ (times)	16,511.13	28,434.37	30,138.15	75,086.65
	CPUE (tons)	4.33	1.61	2.00	7.94

Province are eliminated from those from Oshima, as the latter reasonably include the squids migrating southward from northern Japan Sea. The amount of this elimination is less than 5% of total catches from Oshima Province in every year.

In Table 6 are given annual autumnal catches of squids (C) by line fishing since 1954 in the waters of eastern (from August to November) and southern

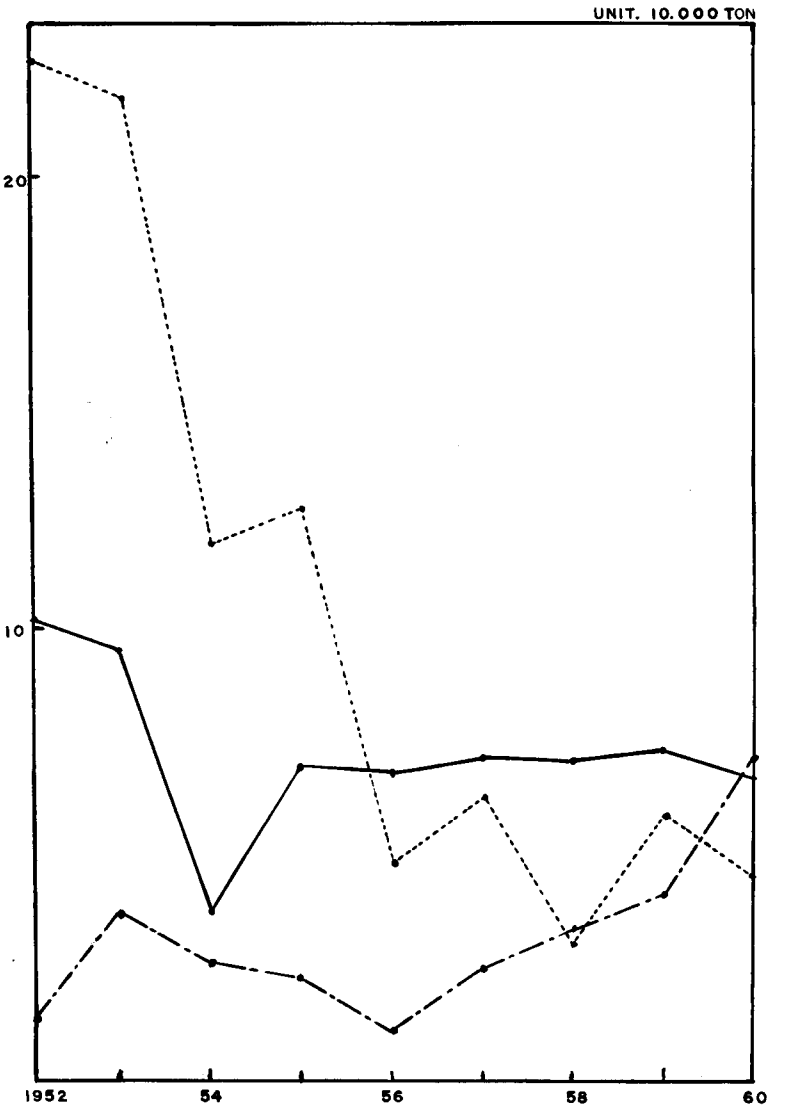


Fig. 6. Sequent fluctuation of the annual catches of autumnal squids from August to December in waters of eastern and southern Hokkaido and Sanriku district in 1952-1960. — — — eastern Hokkaido, - - - - southern Hokkaido, ——— Sanriku district

Hokkaido, and Sanriku district (latter two cover from September to December), numbers of trips (N), estimated numbers of trips ($\tilde{X}_0$) and CPUE. Catches above given are graphed in Fig. 6, number of trips in Fig. 7, $\tilde{X}_0$ in Fig. 8 and CPUE in Fig. 9.

As shown in Fig. 6, squid catches from southern Hokkaido show irregular fluctuation, exhibiting a gradual decrease from the peak 23×10^4 tons in 1951, while those from eastern Hokkaido show a gradual increase from $1\sim2\times10^4$ tons

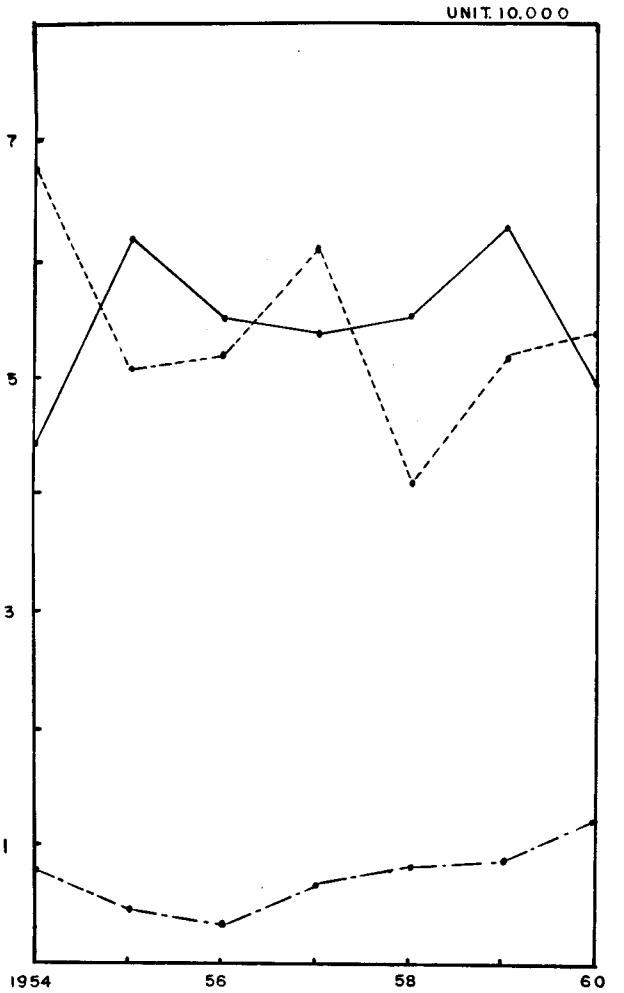


Fig. 7. Sequent fluctuation of the number of trips for fishing autumnal squid between August and December in waters of eastern and southern Hokkaido and Sanriku district in 1954-1960. — — — eastern Hokkaido, - - - - southern Hokkaido, ——— Sanriku district

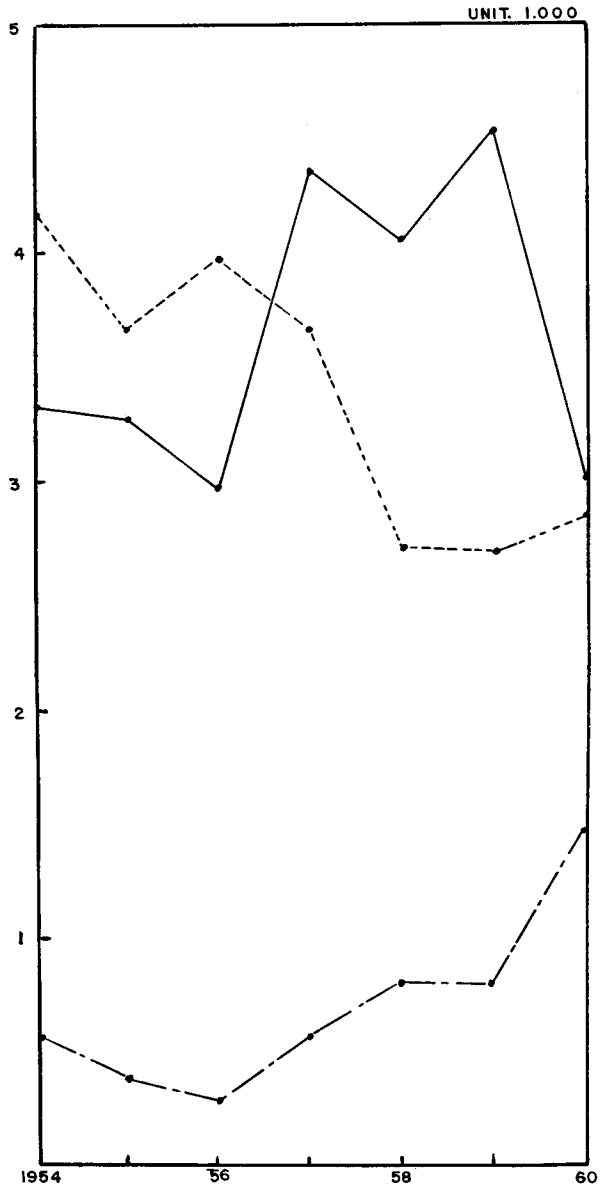


Fig. 8. Sequent fluctuation of the estimated number of trips for fishing autumnal squid between August and December of eastern and southern Hokkaido and Sanriku district in 1954–1960. — — — eastern Hokkaido, - - - - southern Hokkaido, ——— Sanriku district

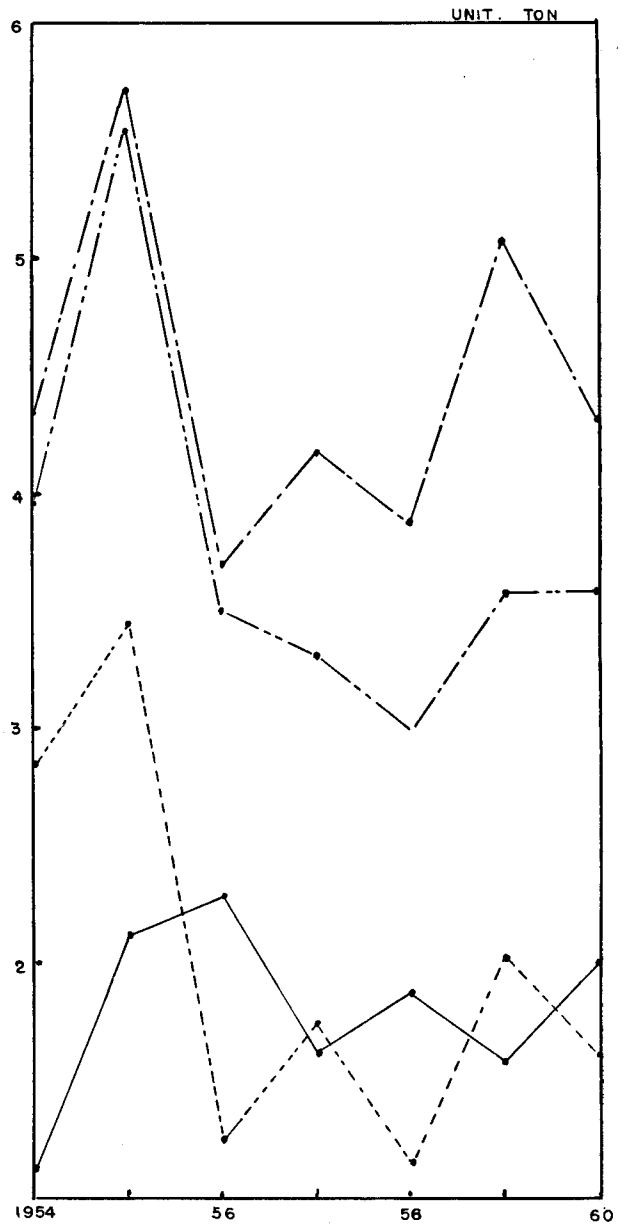


Fig. 9. Sequent fluctuation of annual catches per unit effort (CPUE) in eastern and southern Hokkaido and Sanriku district in the autumnal squid fishing in 1954–1960. — — — eastern Hokkaido, - - - - southern Hokkaido, ——— Sanriku district. — - — - sum of southern Hokkaido and Sanriku district

in 1951 to 1955, attaining to 8×10^4 tons in 1960, thus exceeding the catches from Sanriku district and from southern Hokkaido.

Squid catches from Sanriku district maintain a rather stabilized condition in amount, recording the minimum 4×10^4 tons in 1954, showing ca. 10^5 tons in 1951~1953, and 7×10^4 tons after 1955. Squid catches from southern Hokkaido seas before 1955 were twice as much as those from the Sanriku coast. In Fig. 10 are shown annual percentages of squid catches from those three waters.

As shown in Fig. 7, number of trips in southern Hokkaido sea has decreased gradually from the peak 67×10^3 in 1954, that in the Sanriku sea has showed ca. 5×10^4 on the average, whereas the number in eastern Hokkaido seas has been only about one-fifth of that in the former two seas, though a slight increase has appeared since 1956. In the number of trips, eight grades in the size of fishing boats, nonpowered and powered 1~7, are treated alike, accordingly this number does not denote directly the fishing effort itself. This is the reason why number of trips has been estimated from formula (1).

As understood from Fig. 8, $\tilde{X}_0$ in southern Hokkaido sea showed ca. 38×10^3 until 1957, and ca. 27×10^3 after 1958 indicating a rapid decrease. $\tilde{X}_0$ in Sanriku seas showed ca. 32×10^3 before 1956, 42×10^3 in 1957~1959, and 3×10^4 in 1960. That in eastern Hokkaido sea showed a gradual increase from the bottom 5×10^3 attaining to 14×10^3 in 1960. The value of $\tilde{X}_0$ has fluctuated greatly in the above three sea areas. But the total sum in these three seas shows a rather constant

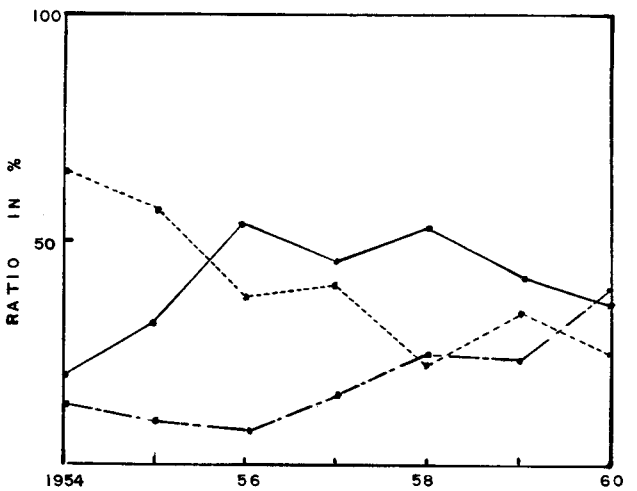


Fig. 10. Sequent fluctuation in the percentage of annual catches of autumnal squid in eastern and southern Hokkaido and Sanriku district in 1954-1960. ——— eastern Hokkaido, - - - - southern Hokkaido, ——— Sanriku district

value of ca. 75×10^3. This is probably due to the number of fishing boats which have come in from other coasts, irrespective of the annual total numbers of boats.

CPUE in each sea is shown in Fig. 9 in order the relative amount of squid stocks to be caught, and correlation coefficient is calculated to ascertain the correlation of the three sea with each other.

Eastern Hokkaido seas to southern Hokkaido seas .....+0.721
Eastern Hokkaido seas to sum of southern Hokkaido seas and Sanriku seas .....+0.750
Eastern Hokkaido seas to Sanriku seas .....+0.067
(degree of freedom 5; level of significance 0.754)
Southern Hokkaido seas to Sanriku seas .....−0.298

CPUE in eastern Hokkaido seas attains to 4~5 tons, while that in Sanriku district and southern Hokkaido seas shows 1~2 tons. That is due to the far higher population density of squids to be caught in eastern Hokkaido seas than in the Sanriku and southern Hokkaido seas. Annual fluctuation value of CPUE is very similar for eastern Hokkaido seas to southern Hokkaido seas and eastern Hokkaido seas to the sum of Sanriku and southern Hokkaido seas. As for correlation coefficient, examples are too few to attain to the level of significance. However, the values of correlation coefficient, +0.721 and +0.750 seems to be very close to the level of significance, showing a positive correlation. Particularly, CPUE in the sum of southern Hokkaido and Sanriku seas shows a very close value to that in eastern Hokkaido seas, representing a similar annual fluctuation between the two. This suggests that population density of squids to be caught in eastern Hokkaido seas decides that in Sanriku and southern Hokkaido seas.

As stated above, squid catches from southern Hokkaido sea were larger before 1955 than those from the Sanriku coast. In Table 7 are shown the annual ratio in percentage of squid catch and CPUE from southern Hokkaido seas to that from Sanriku waters.

As known from Fig. 9, CPUE in southern Hokkaido sea before 1955 also exceeded that in Sanriku seas, and vice versa after 1956. Correlation coefficient

Table 7. Annual ratio in percentage of squid catch and CPUE from southern Hokkaido sea to that from Sanriku sea

Year	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
Ratio (%) of catch, southern Hokkaido	63.09	69.19	70.79	76.13	64.35	42.09	47.15	30.48	44.61	40.70
Ratio (%) of CPUE, southern Hokkaido				71.97	61.83	35.31	51.64	37.87	58.20	44.60

shows a negative correlation, the value being −0.298. This might be understood from the fact, as described above, that on the way of squid migration from eastern Hokkaido sea toward southern Hokkaido and Sanriku seas, the population density of squids to be caught in eastern Hokkaido sea has influence upon that to be caught in southern Hokkaido and Sanriku seas, and accordingly when the population density of squids to be caught in southern Hokkaido sea is high, that in Sanriku sea becomes low, while when that in Sanriku seas is high, that in southern Hokkaido seas becomes low.

4. 2. Index of population abundance

As described above in Chapter II-2, effective effort $\bar{X}$, is calculated from the following formula: $\bar{X}=A\frac{\sum C_i}{\sum(C_iA_i/X_i)}$

Annual values of $\bar{X}$ and $\frac{\bar{X}}{X}$ are given in the following table.

Table 8. Annual values of X and $\frac{\bar{X}}{X}$

Year	1954	1955	1956	1957	1958	1959	1960
$\bar{X}$	66,430.37	74,042.18	71,274.25	124,556.94	120,820.23	122,411.79	131,020.06
$\frac{\bar{X}}{X}$	0.82	1.01	0.98	1.44	1.59	1.52	1.75

As shown in the above table, $\bar{X}$ and $\frac{\bar{X}}{X}$ have increased largely after 1957. This is due to the fact, as known from estimated number of trips shown in Fig. 8, that fishing boats have gathered until 1956 in the fishing grounds in southern Hokkaido seas, but on account of a poor catch in that region in 1956, fishing boats have gathered since 1957 in the fishing grounds in Sanriku seas or eastern Hokkaido seas, thus inducing appropriate distribution of fishing boats and consequently increasing effective fishing effort. As known from Fig. 9, population density of squids to be caught in eastern Hokkaido seas is higher than that in southern Hokkaido and Sanriku seas, therefore effective fishing effort has actually increased since 1957 with great increase in the number of fishing boats in eastern Hokkaido seas.

Index of population abundance N' is given by the following equation (cf. II-2, equaiton (3)).

$$N'=\sum\frac{A_iC_i}{X_i}$$

The annual values of N' and $\frac{N'}{C}$ are given in the following Table 9.

Table 9. Annual values of N' and $\frac{N'}{C}$

Year	1954	1955	1956	1957	1958	1959	1960
N'	18,870,543	25,898,190	17,440,866	17,429,545	16,109,835	20,449,528	18,460,141
$\frac{N'}{C}$	103.74	173.75	135.22	109.66	115.62	118.51	103.94

As given above, the value of N' is approximately $16\sim18\times10^6$ except 1955, and that of $\frac{N'}{C}$ is 103~135, about 100 times as much as the amount of catch. This represents a rather stagnant condition of annual migrating squid stock in southern Hokkaido seas. In 1955, as known from the value of CPUE given in Fig. 9, population density was very high, indicating an abundant squid stock which has migrated in southern Hokkaido, and showing a good accordance with the value of N'.

4. 3. Boundary zones occurring in the southeastern regional sea of Hokkaido

The branch stream of the Tsushima Warm Current which flows eastward into the Tsugaru Straits is called the Tsugaru Warm Current. The situation of boundary zones which are raised between the Tsugaru Warm Current and other water masses in regional seas off southeastern Hokkaido is determined by the balance of their strength. Surface water masses seen in this regional sea are divided into three, water mass derived from the Tsugaru Warm Current, the Oyashio, and the Kuroshio (Transition Areas). The quantity of proportion of these three water masses are controlled by their seasonal and annual variation of flow. Their location also governs the formation of fish shoals and fishing grounds thereof.

The writer has attempted to clarify the correlation between the migration of squid shoals which constitute a main fishery resource and hydrographic conditions in the water masses, on the basis of data derived from observations on hydrographic conditions during about ten years, the streaming conditions of the Tsugaru Warm Current and the location of boundary zones. The depth of the Tsugaru Warm Current which flows into the seas of this region is presumed to be shallower than ca. 200 m as viewed from vertical distribution of water temperature and chlorinity, and T-Cl diagram (cf. 'Kaiyo-Sokuho', or Prompt Reports on Oceanography, No. 36~68). Furthermore the writer has calculated to horizontal distribution of cumulative temperatures of the upper 200 m layer in the seas of this region in March, May, August, and November in 1951~1960.

On the basis of the above data, the distributional form of the Tsugaru Warm

Current is divided into the streaming form and the stagnant form. Flowing eastward into the Tsugaru Straits from its eastern entrance the Tsugaru Warm Current changes its direction toward southeast midway between Esan and Cape Erimo, then turning right from south to southwest, reaches the Sanriku coast, and flows south farther along this coast. This is the streaming form of the distribution of the Tsugaru Warm Current, and the water masses occur in rather surface layer. In the stagnant form, the current turns right similarly to the former near the mid-point between Esan and Cape Erimo. When the Kuroshio front lying in the southern part of Sanriku approaches very near the shore, if the influence of Oyashio is strong, reaching the Sanriku coast, or southward flowing of the Tsugaru Warm Current is impeded by some factors, it made a clockwise vortex in the southeastern regional seas of Hokkaido. The right vortex formed in the northern hemisphere forms a sinking stream swelling gradually. Needless to say, in any case, boundary zones will be constructed at the margins.

For convenience of investigating the influence of the Tsugaru Warm Current

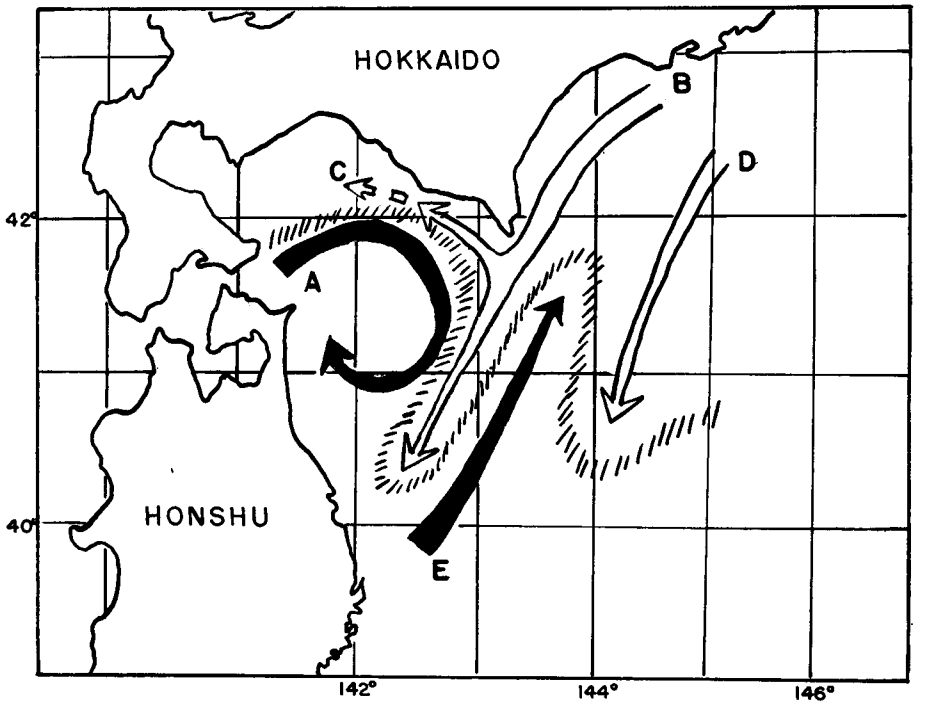


Fig. 11. Schematic representation of the hydrographic conditions near the Tsugaru Warm Current zone (Type A—Stagnating type No. 1). A—Tsugaru Warm Current, B—Coastal Branch of the Oyashio, C—Hidaka Branch from the Coastal Branch of the Oyashio, D—1st Branch of the Oyashio, E—Warm water masses in the Transition Area

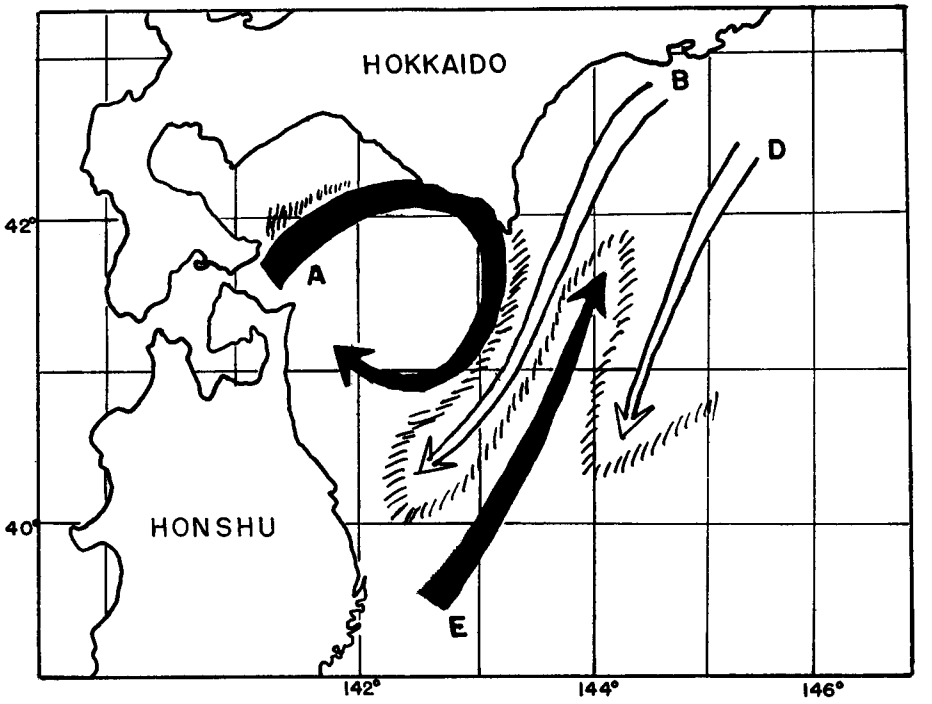


Fig. 12. Schematic representation of the hydrographic conditions near the Tsugaru Warm Current zone (Type B—Stagnating type No. 2). A—Tsugaru Warm Current, B—Coastal Branch of the Oyashio, E—Warm water masses in the Transition Area

upon the formation of fishing grounds for squids off southern Hokkaido and in Sanriku regional seas, that current my be classified into the following four types.

Type A: Stagnating type 1. As shown in Fig. 11, since the influence of the current is rather weak, its outer margin does not reach to the Hidaka coast; a shore branch of the Oyashio which flows southward along Tokachi shore turns right near Cape Erimo, and extends to Esan regional sea past the coasts of Hidaka and Iburi.

Type B: Stagnating type 2. Influence of the current reaches the Hidaka coast, much stronger and broader than Type A; the shore branch of the Oyashio which flows southward along the coast of Tokachi is checked near Cape Erimo from flowing along the Hidaka coast (Fig. 12).

Type C: Flowing southward type 1. Range of influence of the Tsugaru Warm Current is rather narrow in the surface layer, similiarly to the case of Type A. Nevertheless, the depth of the current is considerably shallower than that of Type A, as the Tsugaru Warm Current flows southward along the Sanriku

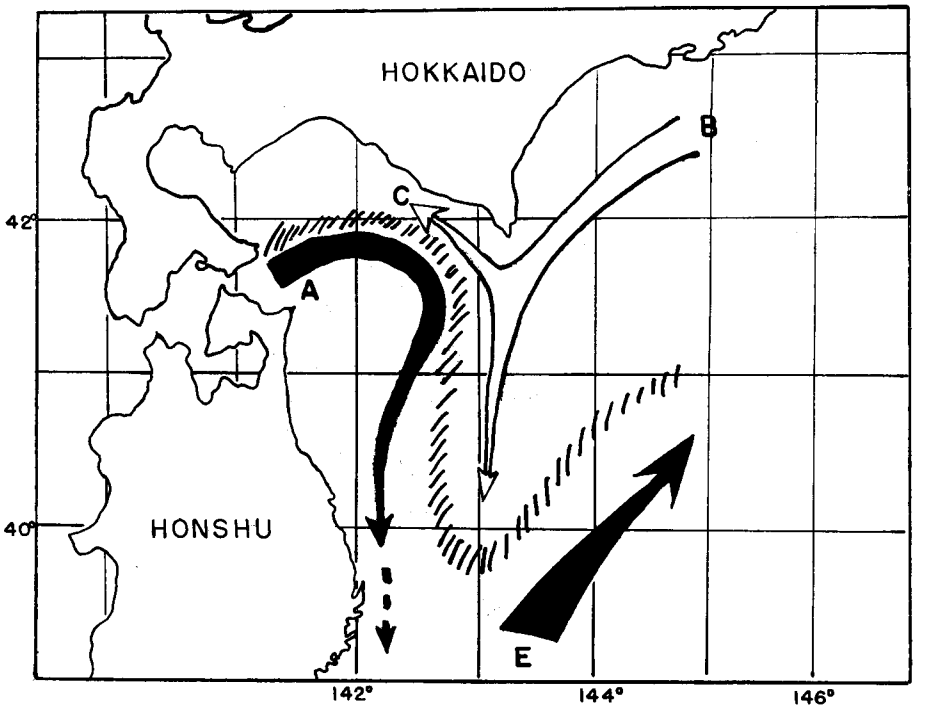


Fig. 13. Schematic representation of the hydrographic conditions near the Tsugaru Warm Current zone (Type C—Flowing southward type No. 1). A—Tsugaru Warm Current, B—Coastal Branch of the Oyashio, E—Warm water masses in the Transition Area

coast (Fig. 13).

Type D: Flowing southward type 2. Range of influence in surface layer reached as far as the Hidaka coast, as in the case of Type B; the shore branch of the Oyashio is checked near Cape Erimo from flowing along the Hidaka coast also as in the case of Type B above. Nevertheless, the depth of the Tsugaru Warm Current is much shallower than that of Type B, as the current flows southward along the Sanriku coast (Fig. 14).

According to the classification described above, the distribution of hydrographic conditions of the Tsugaru Warm Current in August and November, especially important fishing seasons of squids which migrate southward, from 1951 to 1960 is classified into the following, judging from direction and velocity of the current in surface layer as measured by GEK (geomagneto-electro-kinetograph), from density current calculated (cf. 'Kaiyo Sokuho' or Prompt Reports, No. 36~68), and horizontal distribution of cumulated mean water temperature in tht layer less than 200 m deep.

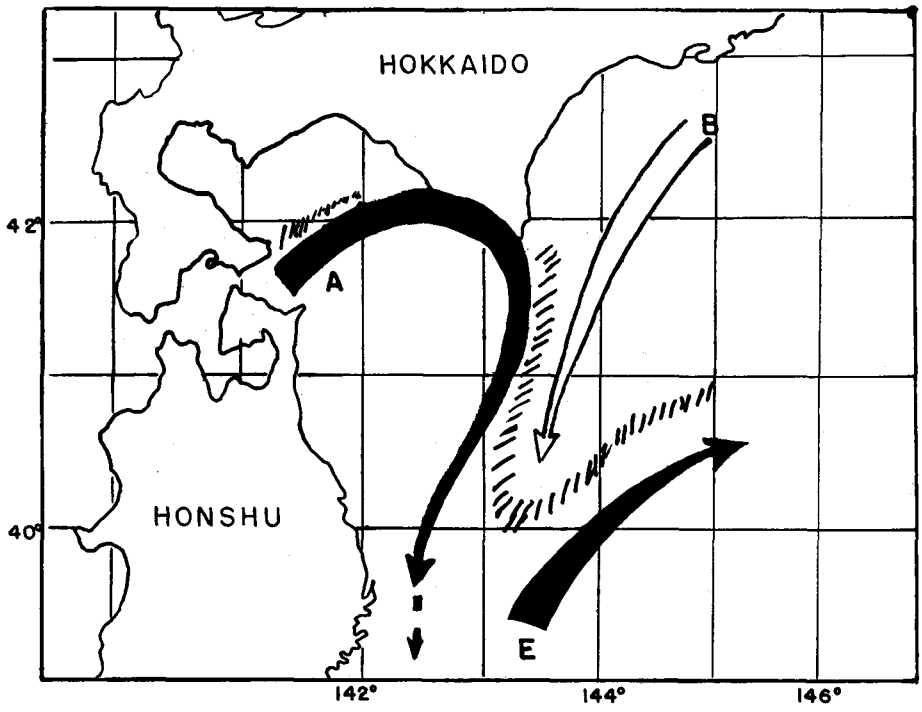


Fig. 14. Schematic representation of the hydrographic conditions near the Tsugaru Warm Current zone (Type D—Fowing southward type No. 2). A—Tsugaru Warm Current, B—Coastal Branch of the Oyashio, E—Warm water masses in the Transition Area

August	Type A:	1951, 1952, 1954, 1957, 1960.
	Type B:	1956, 1958, 1959.
	Type C:	1953.
	Type D:	1955.
November	Type A:	1951, 1952.
	Type B:	1956, 1958.
	Type C:	1953, 1954, 1957, 1959, 1960.
	Type D:	1955.

Horizontal distribution of water temperature and chlorinity in layers at 0 m, 100 m, 200 m, and 300 m and vertical distribution of them to the east of Cape Shiriya in the typical years listed above are shown in the following figures. August, 1957 (Figs. 15, 16) belongs to Type A, which is influenced to the depth of 100 m and 200 m by the Tsugaru Warm Current. This illustration shows of the Stagnating type; the Tsugaru Warm Current does not extend to the Hidaka coast. November, 1956 (Figs. 17 and 18) shows Type B; the current stretches

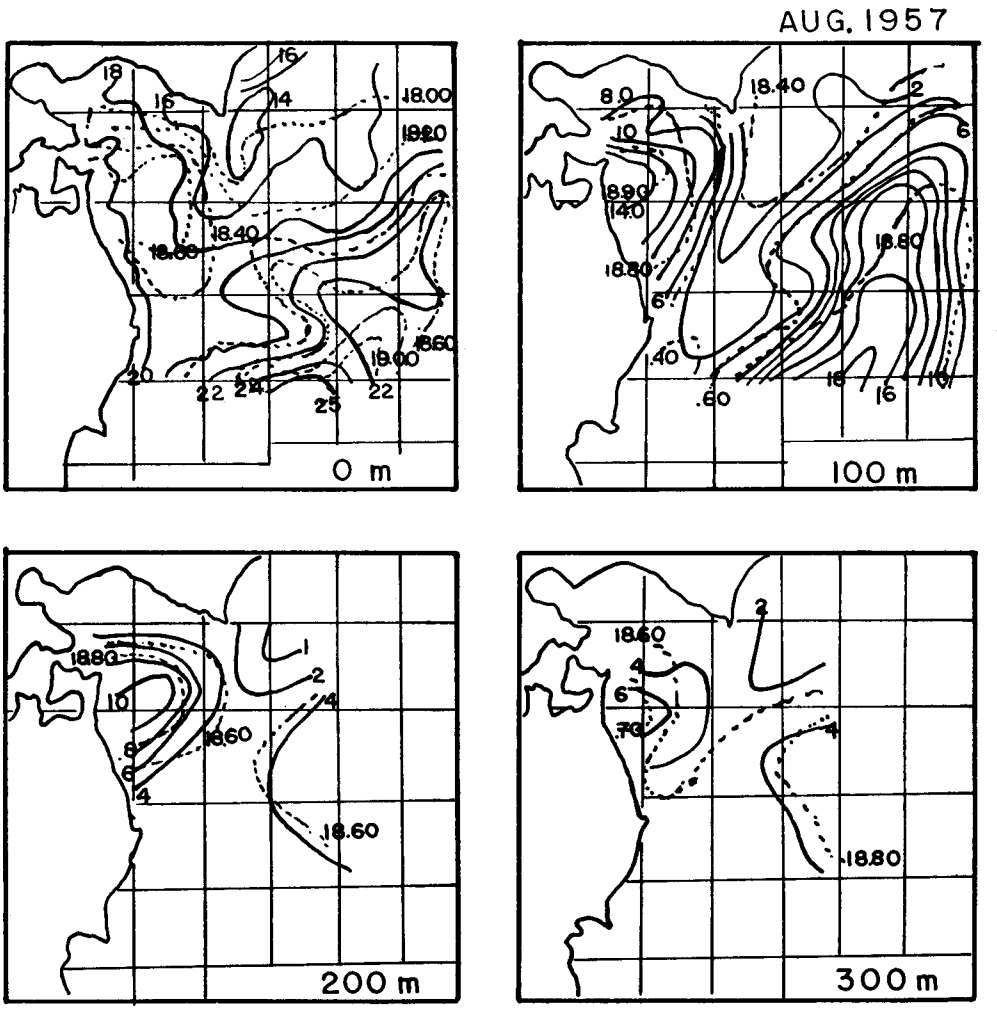


Fig. 15. Horizontal distribution of water temperature and chlorinity at surface, 100 m, 200 m and 300 m in depth in August 1957 (Type A). ——— water temperature, - - - - chlorinity

broadly as far as the Hidaka coast. A shore branch of the Oyashio extends to the waters of the Sanriku region; the Tsugaru Warm Current is prevented from flowing south, so a sinking is formed as deep as 300 m layer. November, 1951 (Figs. 19, 20) shows Type C; a shore branch of the Oyashio extends past Cape Erimo almost all over the regional waters to the southeast of Hokkaido, so the Tsugaru Warm Current remains only between Cape Shiriya and the Sanriku coast. November, 1955 (Figs. 21, 22) illustrates Type D; the current reaches to the Hidaka coast, then flows southward along the coast of Sanriku.

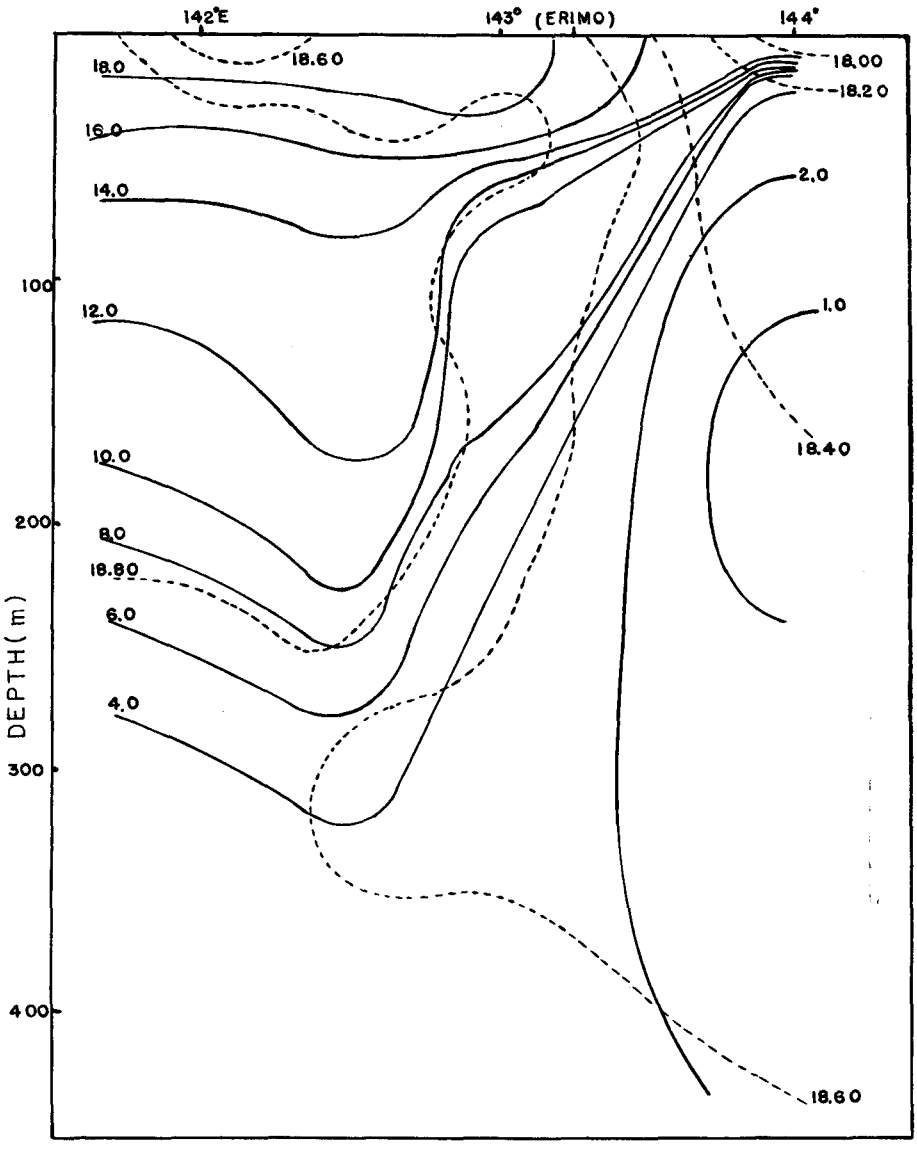


Fig. 16. Vertical section of water temperature and chlorinity in the sea east off Cape Shiriya (Lat 41°-26′N) in August 1957. ——— water temperature, - - - - chlorinity

Forms of distribution of the Tsugaru Warm Current in the seas to the southeast of Hokkaido are classified as mentioned above, while those of other water masses are as follows: The Tsugaru Warm Current which has flowed through the eastern entrance to the Tsugaru Straits flows on eastward. Consequently in the Esan regional water which faces the outer margin of the current,

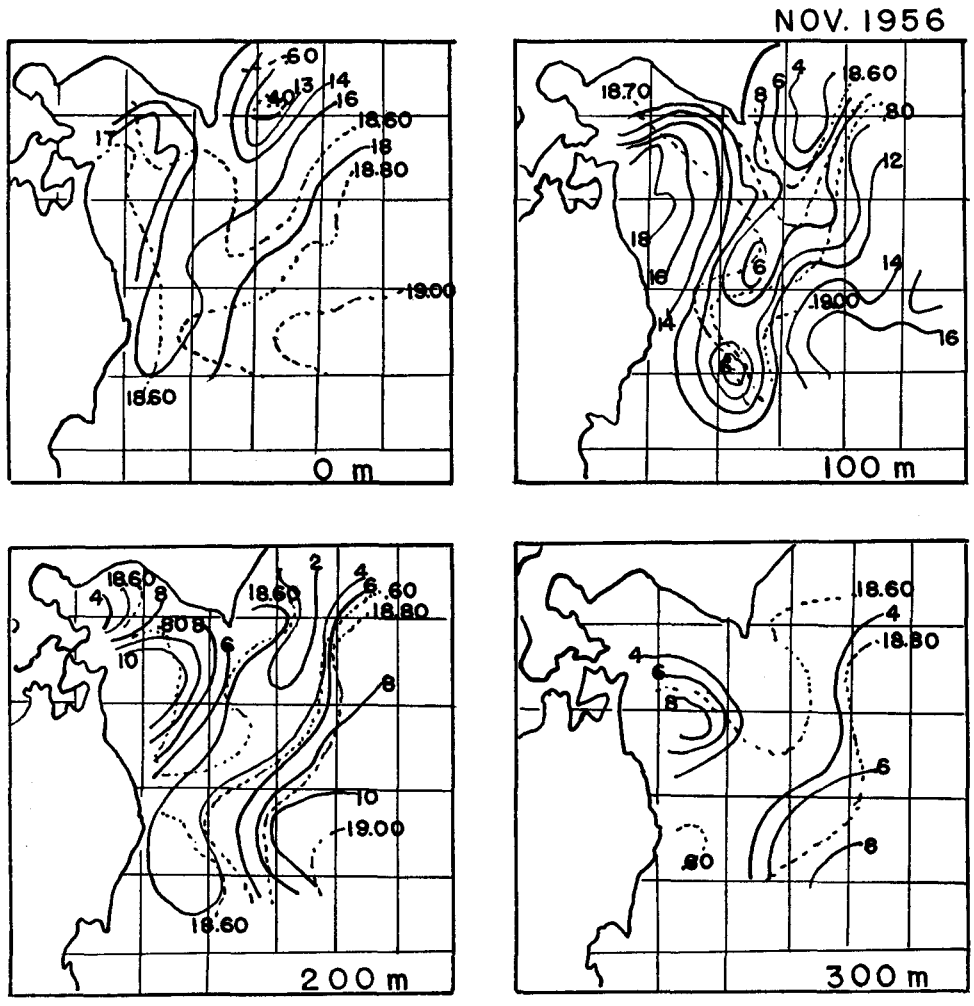


Fig. 17. Horizontal distribution of water temperature and chlorinity at surface, 100 m, 200 m and 300 m in depth in November 1956 (Type B). ——— water temperature, - - - - chlorinity

an anticlockwise vortex is raised, near which an upwelling of cold water masses in mid layer occurs. On the other hand, the Oyashio which has entered Esan regional water from Cape Erimo along the coasts of Hidaka and Iburi stays in that water and after joining the upwelling a marked cold water mass is raised (Figs. 23, 24). Therefore an evident boundary zone is formed in that vicinity.

The phenomenon mentioned above has already been pointed out by the writer *et al.* (1949). The vicissitude of this cold water mass depends upon the strength of the shore branch of the Oyashio, as well as upon the extended range of the Tsugaru Warm Current (*l.c.*).

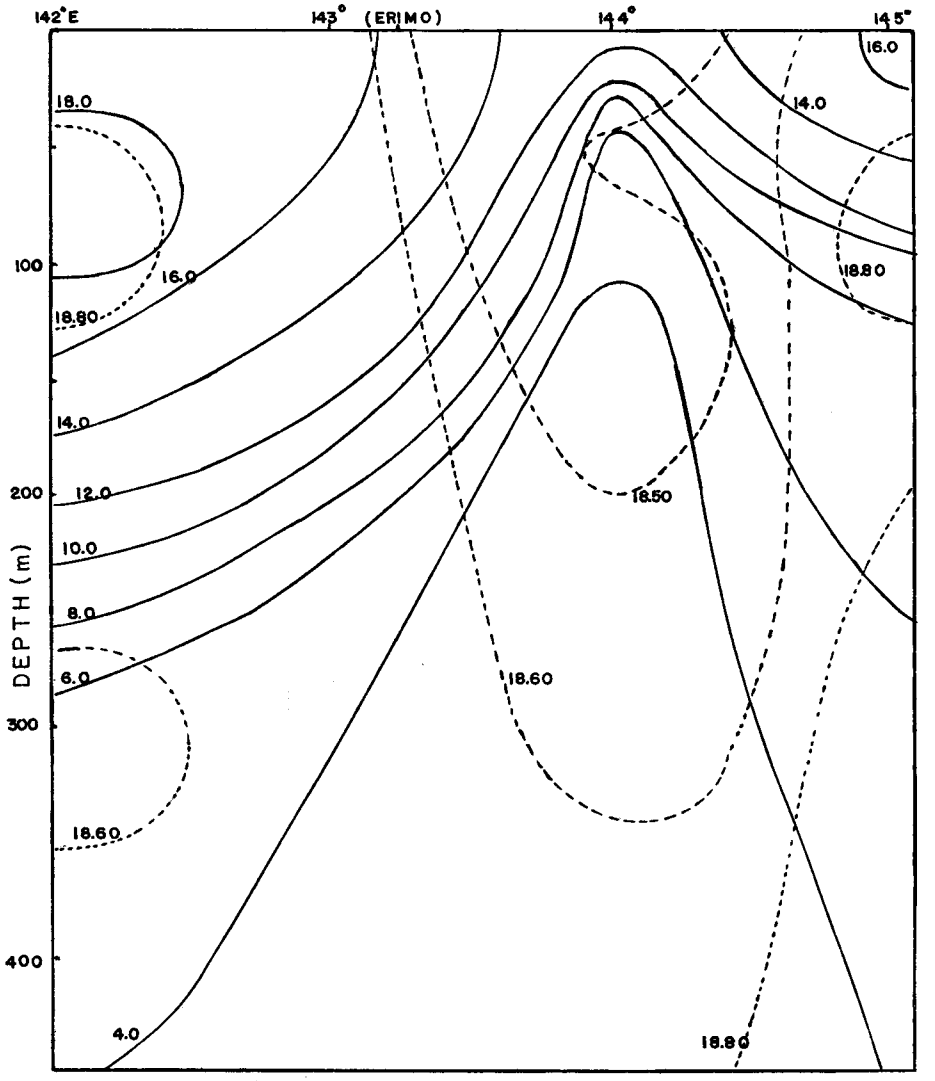


Fig. 18. Vertical section of water temperature and chlorinity in the sea east off Cape Shiriya (Lat 41°-26′N) in November 1956. ——— water temperature, - - - - chlorinity

Off Shiranuka, on the Shimokita peninsula, Aomori prefecture, another upwelling is caused by hydrogeographical factors (Fig. 25).

In order to analyse the hydrographic conditions of water masses in the sea to the southeast of Hokkaido in August, 1960, a T-Cl diagram (Fig. 26) and a dynamic topographical chart (Fig. 27) of the sea surface in dynamic meters referred to the 300-decibar surface, are shown here. Density current of the Tsugaru Warm Current between St. 10 and 12 (20 miles apart) introduced from

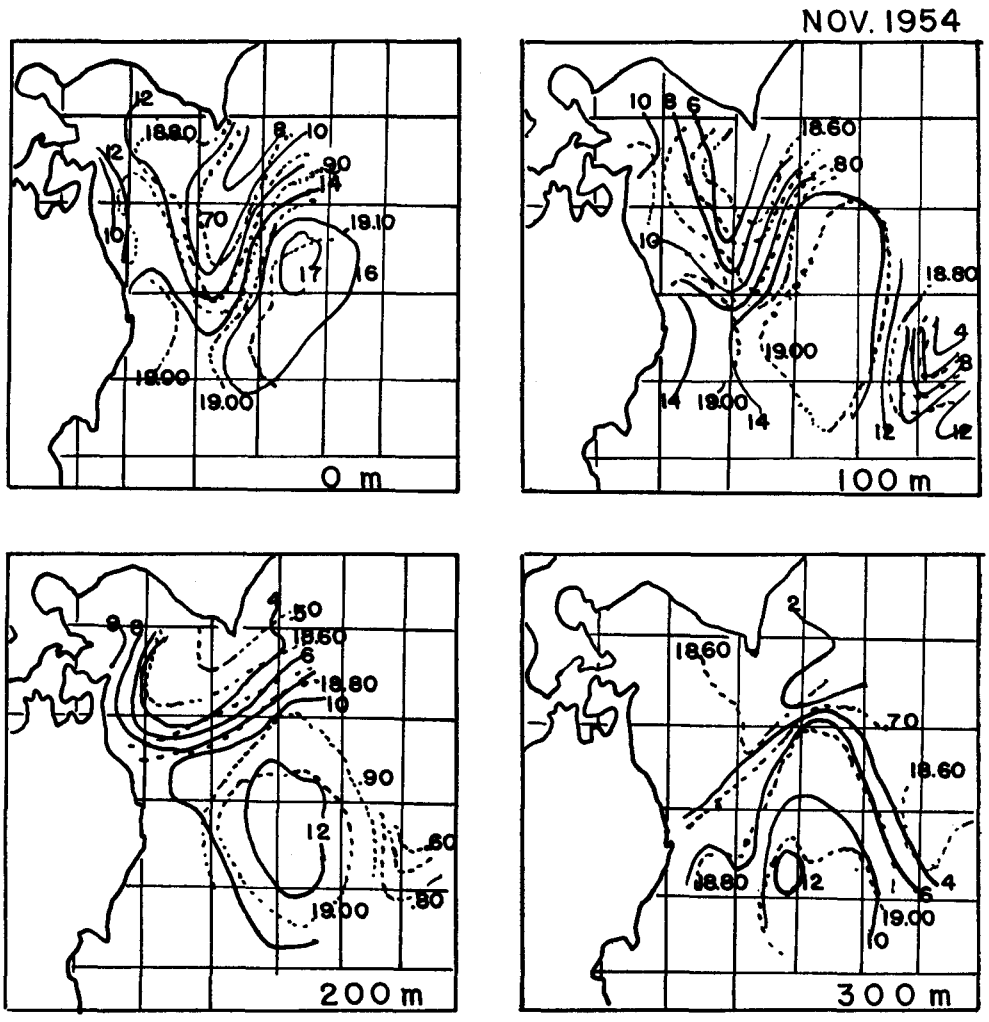


Fig. 19. Horizontal distribution of water temperature and chlorinity at surface, 100 m, 200 m and 300 m in depth in November 1954 (Type C), ——— water temperature, - - - - chlorinity

the above is 57.8 cm/sec. (1.12 knot).

The shore branch of the Oyashio commonly flows down the coasts of Kushiro and Tokachi toward Cape Erimo. However, a peculiar phenomenon appeared in August, 1960 as illustrated in Fig. 28, in which a predominating warm water mass of the Kuroshio stayed solitarily for a long period off the coast of Kushiro, and the shore branch of the Oyashio flowed southward off the water mass. This is a single instance in the past records of hydrographic conditions.

Assuming that the location of a current rip shows a rough demarcation of

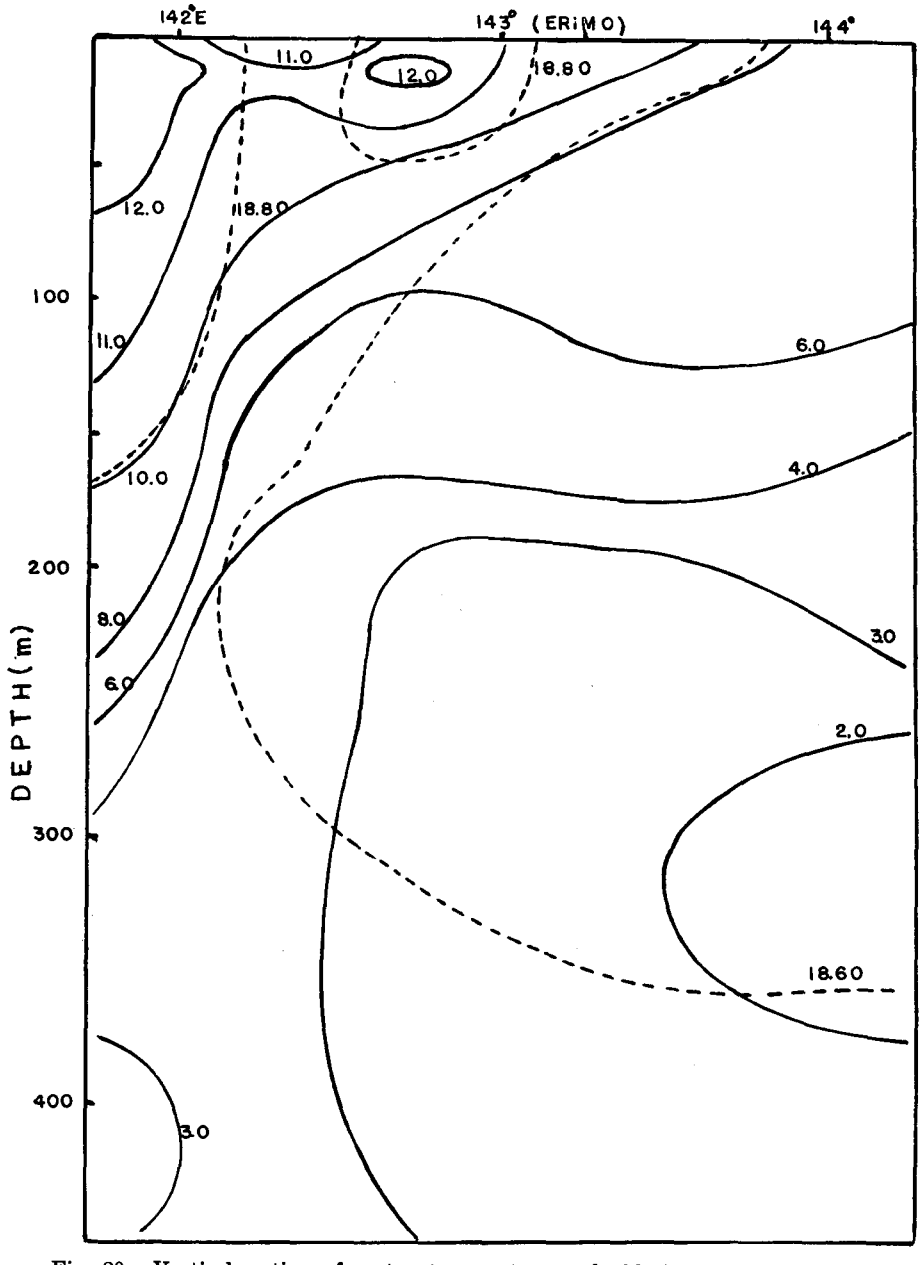


Fig. 20. Vertical section of water temperature and chlorinity in the sea east off Cape Shiriya (Lat 41°-26'N) in November 1954. ——— water temperature, - - - - chlorinity

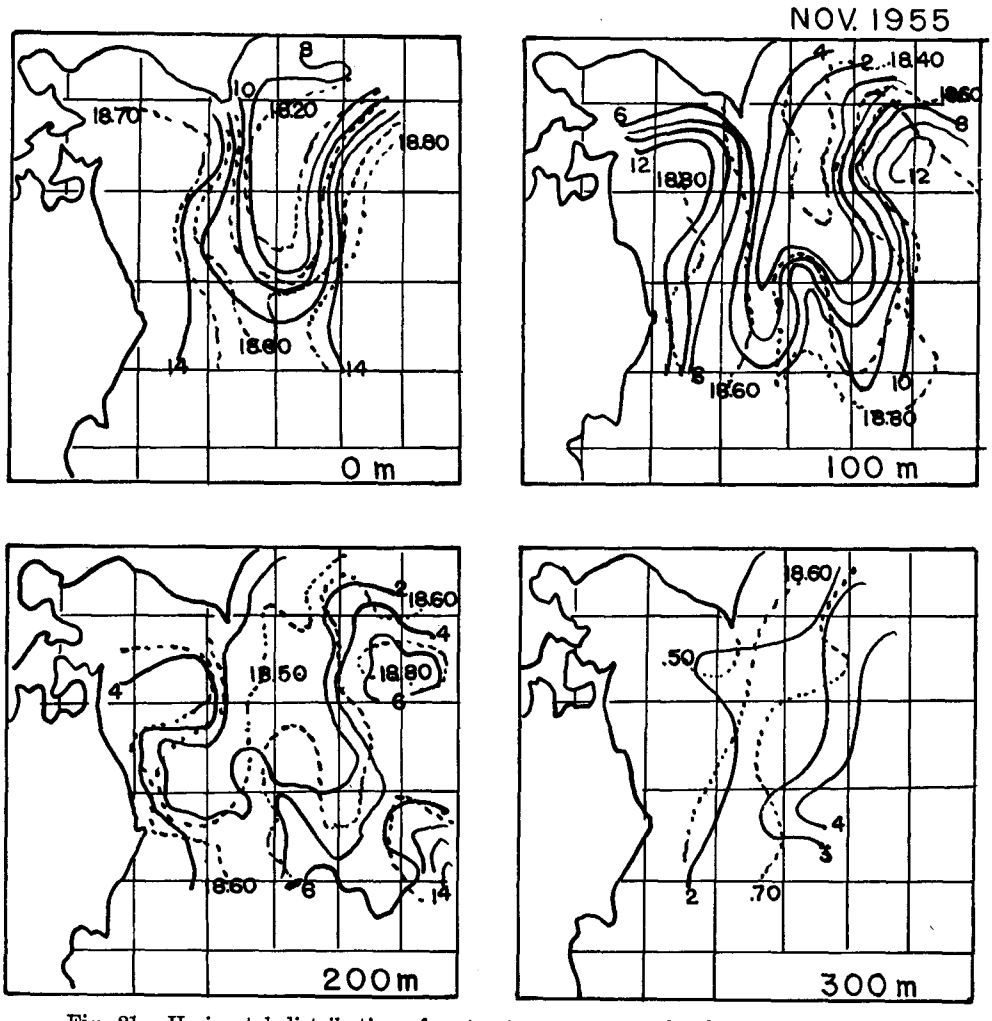


Fig. 21. Horizontal distribution of water temperature and chlorinity at surface, 100 m, 200 m and 300 m in depth in November 1955 (Type D), ——— water temperature, - - - - chlorinity

boundary zones, the writer made total 15 investigations on the actual distributions of current rips by airplane once a month from May to December in 1960 and 1961. Comparing the observations from the above flights with the data obtained from the oceanographic observations, the writer has confirmed that the locations of current rips show roughly the boundary zones formed by the Tsugaru Warm Current and the shore branch of the Oyashio. A current rip is raised markedly in waters where the Tsugaru Warm Current near Esan joins cold water masses arising at the outer margin of the former. Another one also is raised evidently

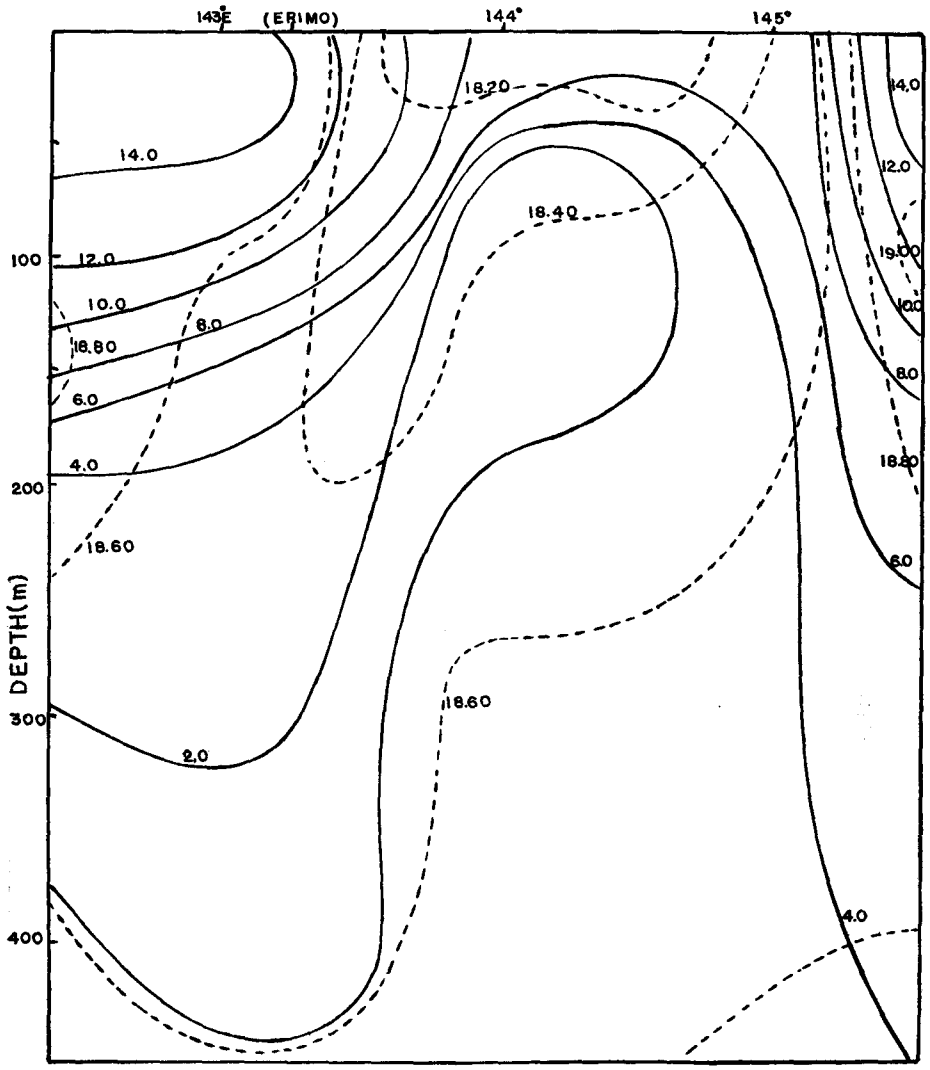


Fig. 22. Vertical section of water temperature and chlorinity in the sea east off Cape Shiriya (Lat 41°-26′N) in November 1955. ——— water temperature, - - - - chlorinity

near Cape Erimo where the Tsugaru Warm Current joins the Oyashio (Figs. 29 and 30).

4. 4. Peculiar hydrographical phenomena in southeastern sea of Hokkaido as observed by means of ultra sonic wave

DSL (Deep Scattering Layer) denotes figures made on the recording papers by reflection from sea bottom of something other than fish shoals when ultra

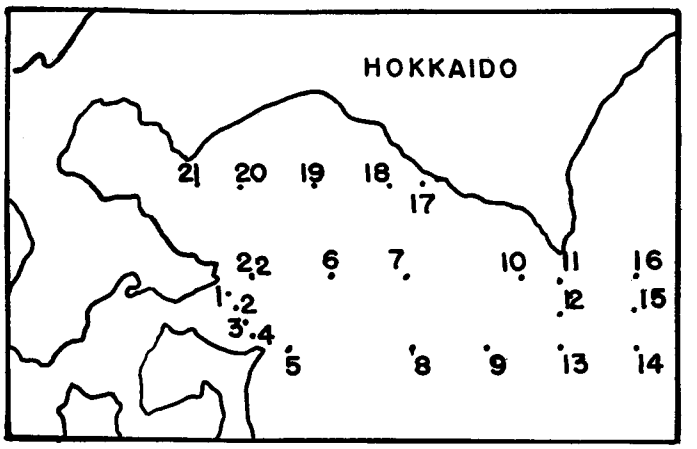


Fig. 23. Chart indicating stations of the oceanographical observations in September 1960

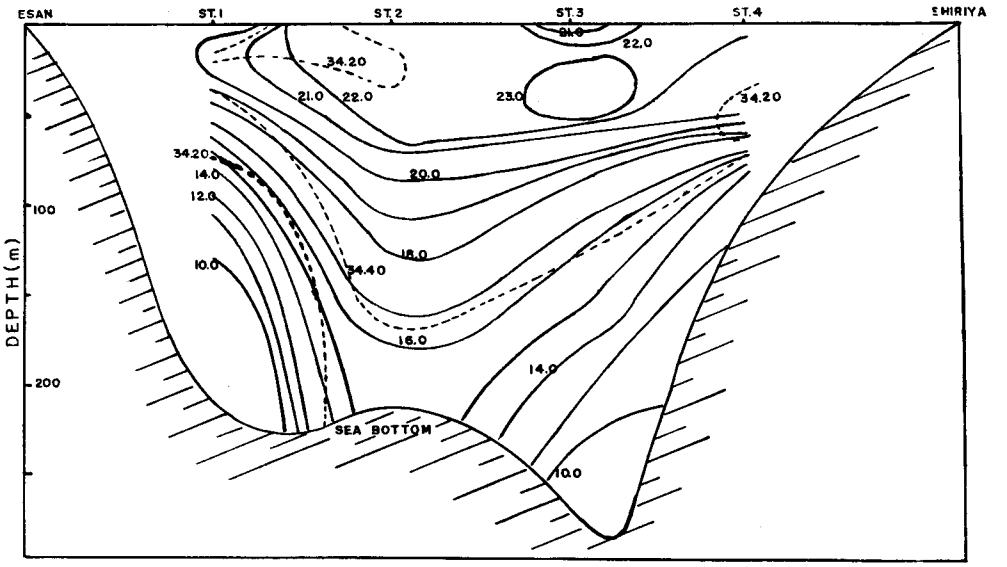


Fig. 24. Vertical section of water temperature and salinity in the water between Esan and Cape Shiriya in September 1960. ——— water temperature, - - - - salinity

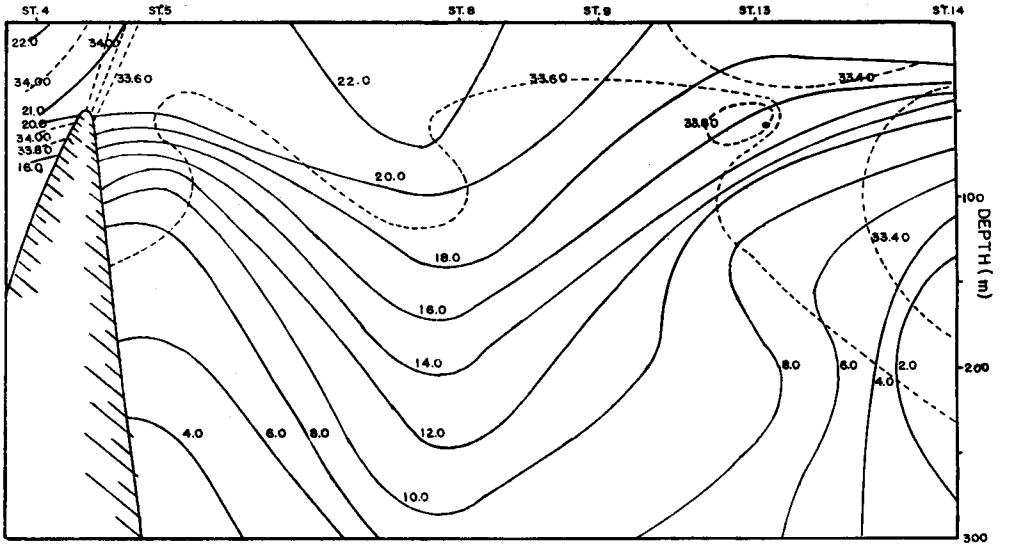


Fig. 25. Vertical section in the east off Cape Shiriya (Lat 41°-26′N) in September 1960. ——— water temperature, - - - - salinity

sonic waves are propagated in the sea. DSL is caused by physical phenomena which are reflections from thermoclines of discontinuous layers of chlorinity, and also by biological phenomena which are dispersions of sound raised by planktons, fish larvae, and other micro-organisms in the water. In both cases, of physical origin and the biological one, two kinds of figures are seen, one is formed independently, and the other doubly, one above another.

The writer has studied the distribution of DSL in the sea to the southeast of Hokkaido from the view point of fishery science interest in boundary zones (Figs. 31, 32 and 33). DSL in that sea is observed distributed mainly in the outer margins of extensions of the Tsugaru Warm Current, that are near the boundary zones, particularly near water masses of the Oyashio (Fig. 34). Resulting from hydrographic conditions, quantity of planktons, and light intensity as shown in Figs. 35, 36, 37 and 38, no DSL in that sea is considered to be caused by reflections with physical factors. Variation of depth of DSL is seen to have no correlations with physical conditions.

Quantities of planktons given in Figs. 35, 36 are tabulated as caliber of cylinders by their wet weights which were collected in each layer, and the data shown in Fig. 37 indicate their wet weights. In both cases, planktons are very abundant in quantity in DSL, and most of the planktons collected belong to Zooplanktons as known in Figs. 39 and 40. Predominating species among them are crustacea such as *Euphausia* and *Parathemisto*.

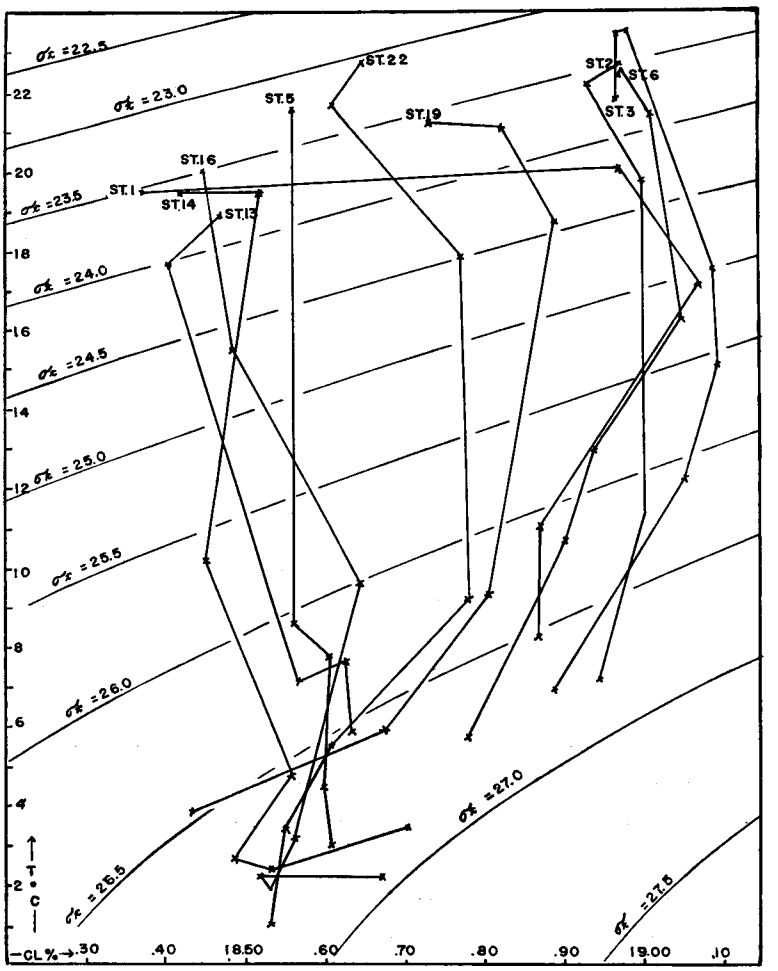


Fig. 26. T-Cl diagram in the southeastern regional waters of Hokkaido in September 1960

In Table 10 and Fig. 41 are shown total numbers of individuals, average body lengths and quantity in 1 m^3 water of *Euphausia pacifica* and *Parathemisto japonica* collected in DSL and reflection loss of DSL shown in Figs. 35 and 36.

It has already become clear that zooplanktons make diurnal movement, rising before nightfall, and sinking toward daybreak. Comparing the species and quantities of planktons in DSL with those outside DSL, and from diurnal change of DSL and hydrographic conditions, the writer has believed firmly that DSL is actually caused by zooplanktons. This finding by the writer agrees well with the observations by Dietz (1948), Boden (1950) and Komaki (1956). Boden (1950), Moore (1950) and Tucker (1951) also observed zooplanktons in DSL mostly

Table 10. Number of individuals, wet weight, body length of *Euphausia pacifica* and *Parathemisto japonica* collected in various layers of DSL shown in Figs. 35, 36 and reflection loss of DSL

Classification No.	Settling volume (cc)	Wet weight (g)	Wet weight (g/m^3)	Number of individuals	Number of distribution (number/m^3)	Body length (mm)	Reflection loss (db)
1	8.7	1.38	1.943	*E* 55 *P* 5	77.46 7.04	7.45 4.00	58.0
2	6.2	1.07	0.602	*E* 68 *P* 2	45.07 3.76	7.05 1.05	58.0
3	12.1	1.74	0.612	*E* 136 *P* 4	47.88 1.41	8.39 3.75	52.0
4	3.0	0.62	0.873	*E* 59 *P* 4	83.09 5.63	5.39 2.75	58.6
5	5.2	1.02	0.718	*E* 73 *P* 21	34.27 7.39	12.98 1.24	59.0
6	9.0	1.62	0.456	*E* 127 *P* 0	35.77 0	10.94 0	53.0
7	3.0	0.82	1.154	*E* 53 *P* 15	74.66 21.12	11.57 4.27	58.5
8		55.32	0.134	*E* 3932 *P* 1727	9.51 4.19	9.84 3.62	58.5

E—Euphausia pacifica, P—Parathemisto japonica.

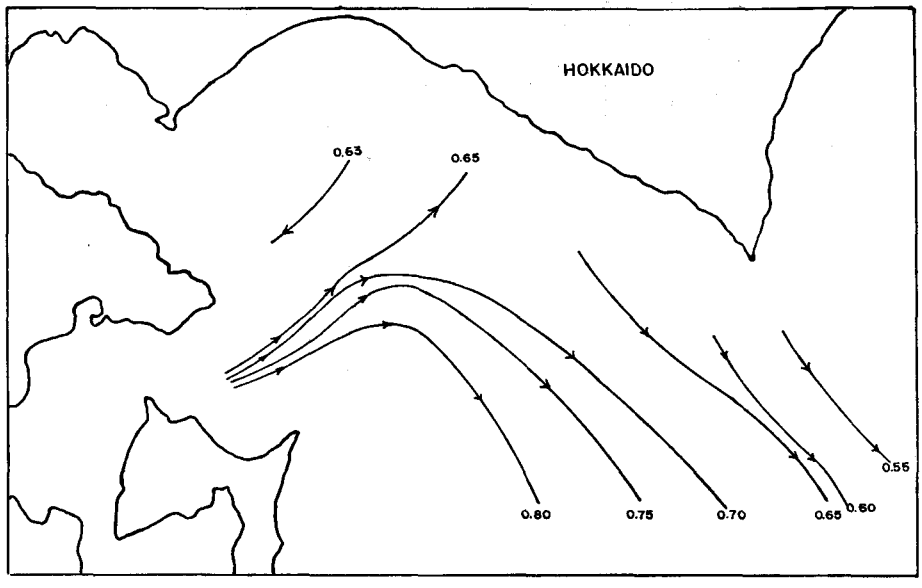


Fig. 27. The geopotential topography of the sea surface in dynamic meters refered to the 300-deciber surface in September 1960

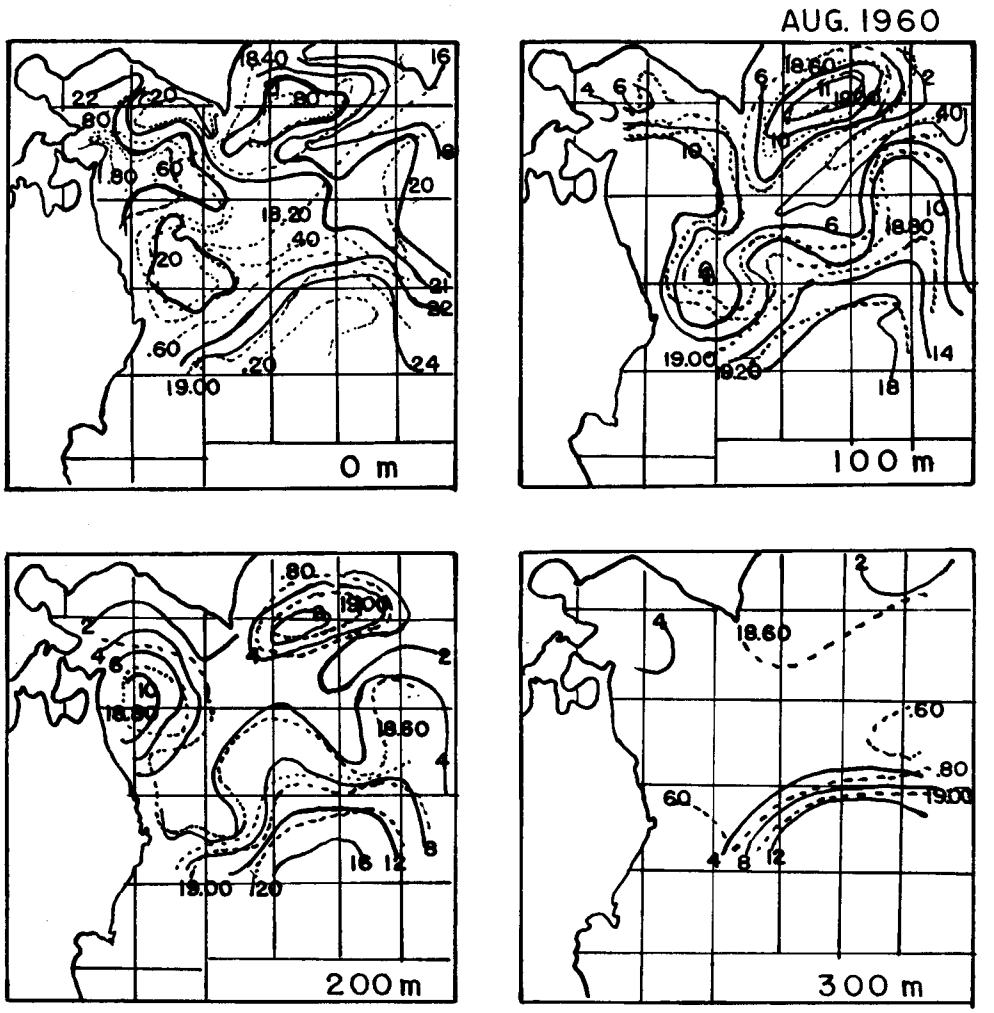


Fig. 28. Horizontal distribution of water temperature and chlorinity at surface, 100 m, 200 m and 300 m depths in August 1960. ——— water temperature, - - - - chlorinity

comprise such crustaceas as euphausiid and others.

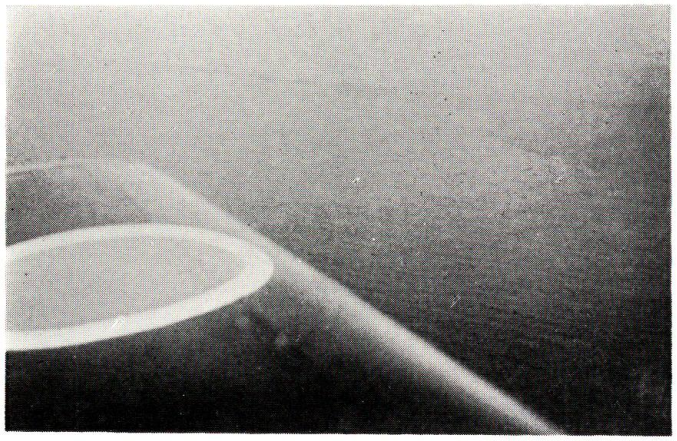
Kokubo (1938) states that zooplanktons show negative phototaxis to an intensive light, and positive one to a weak light. On the basis of his paper, diurnal change of DSL made by zooplanktons seems to be due to submarine illumination. To check that opinion this fact, the writer made some observations on DSL and submarine illumination from a drifting boat between 8.00 a.m. and 7.00 p.m. near Cape Erimo on August 20, 1961 (Fig. 42). In these observations it was made clear that DSL is distributed parallel to 1 lux isolumes, though

(A)

(B)

(C)

Fig. 29 (A–C). Air photographs indicating the current rips in the southeastern waters in Hokkaido. A, B—Near Esan. C—Between Esan and Cape Erimo



(D)

(E)

(F)

Fig. 29 (D–F). Air photographs indicating the current rips in the southeastern waters in Hokkaido. D—Between Esan and Cape Erimo. E, F—Off Cape Erimo

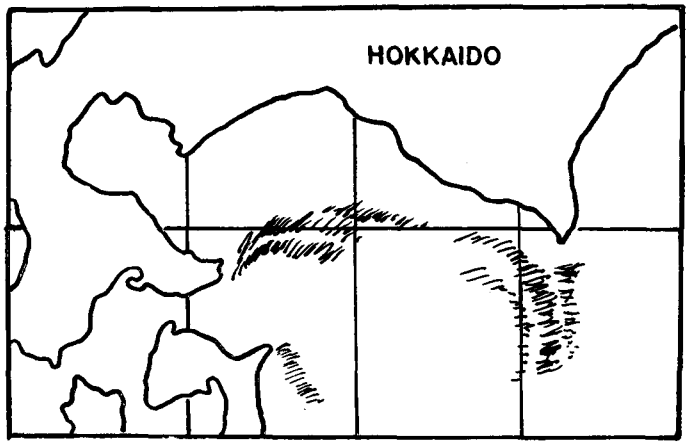


Fig. 30. Rough air sketches of current rips in southeastern waters off Hokkaido

photo-intensity could not be observed in the uppermost and lower-most layer of DSL, as the capacity of submarine photometer was 0.7 lux.

Provided that submarine illumination declines in exponential function, when 0.7 lux line is elongated in semilog scale (Fig. 42), and submarine illumination of DSL layer is calculated, DSL layer is concluded within in the intensity of 0.2~0.8 lux. No figures of DSL were observed by the writer in water shallower than 100 m depth where submarine illumination exceeds 1 lux in daytime.

From the above observations it was made clear that DSL caused by such crustacea as euphausiid makes diurnally vertical movement which is parallel to isolumes lying between 1 lux and 0.1 lux. The velocity of the movement almost accords with that of submarine isolumes level, showing 0.5 m/min.~1.5 m/min. As regards the water temperature of DSL, no obstacles were recorded to the vertical movement mentioned above between 4°C and 20°C.

V. Discussion

Concerning fishing condition and migration of squid there are available papers by Kawana (1928, 1929, 1930, 1931, 1932 and 1934) and Isahaya (1930, 1931 and 1932); both were working at the Hokkaido Fisheries Scientific Institution. Those studies were carried out in Osima district which provided the main fishing grounds of squid in those days. They pointed out a northern type and a southern one among squid found there, and classified them into Pacific form and Japan Sea one (Kawana, 1932). Ishii (1932) reported two ecological varieties

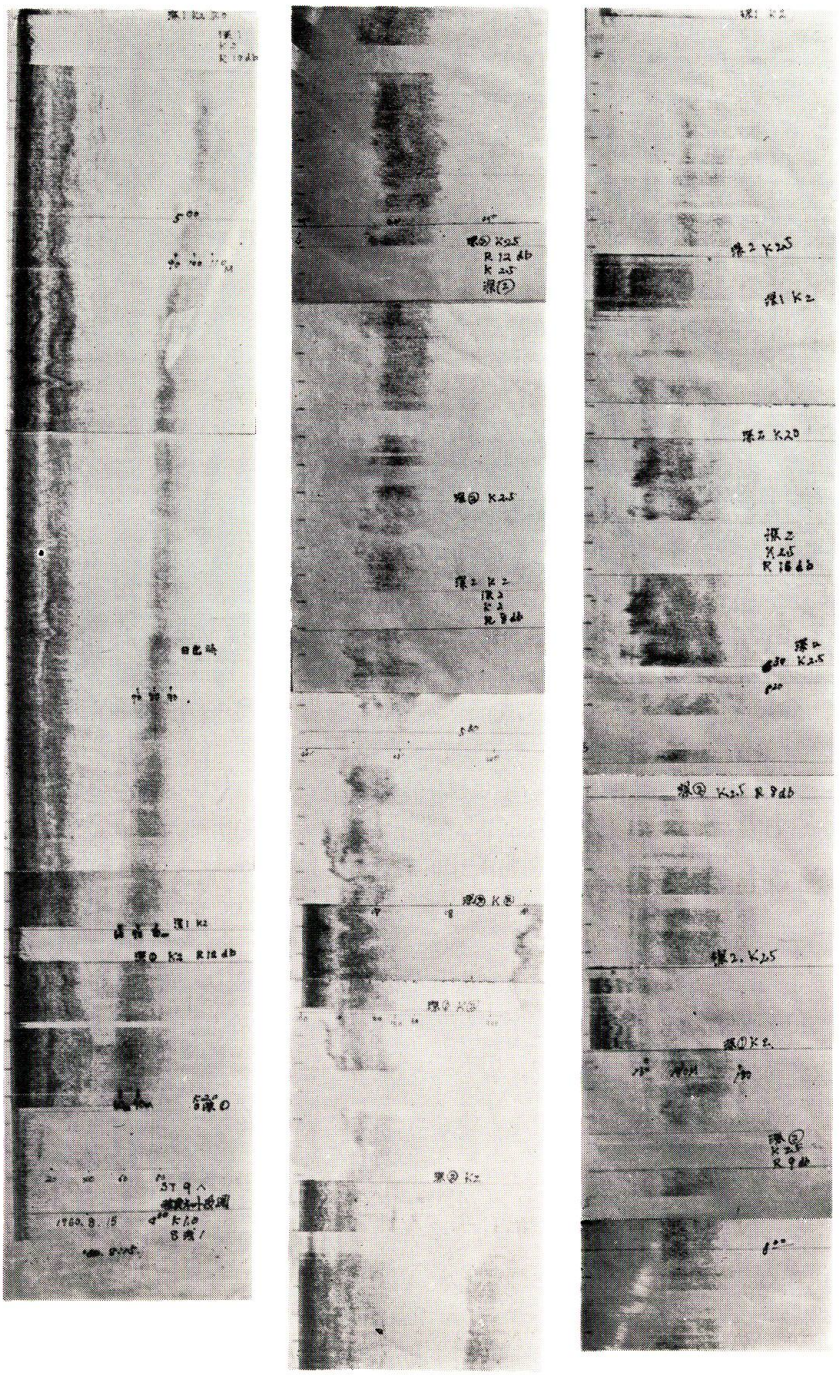


Fig. 31. Echo-image of DSL in the sea adjacent to Cape Erimo in August 1960 (DSL is sinking)

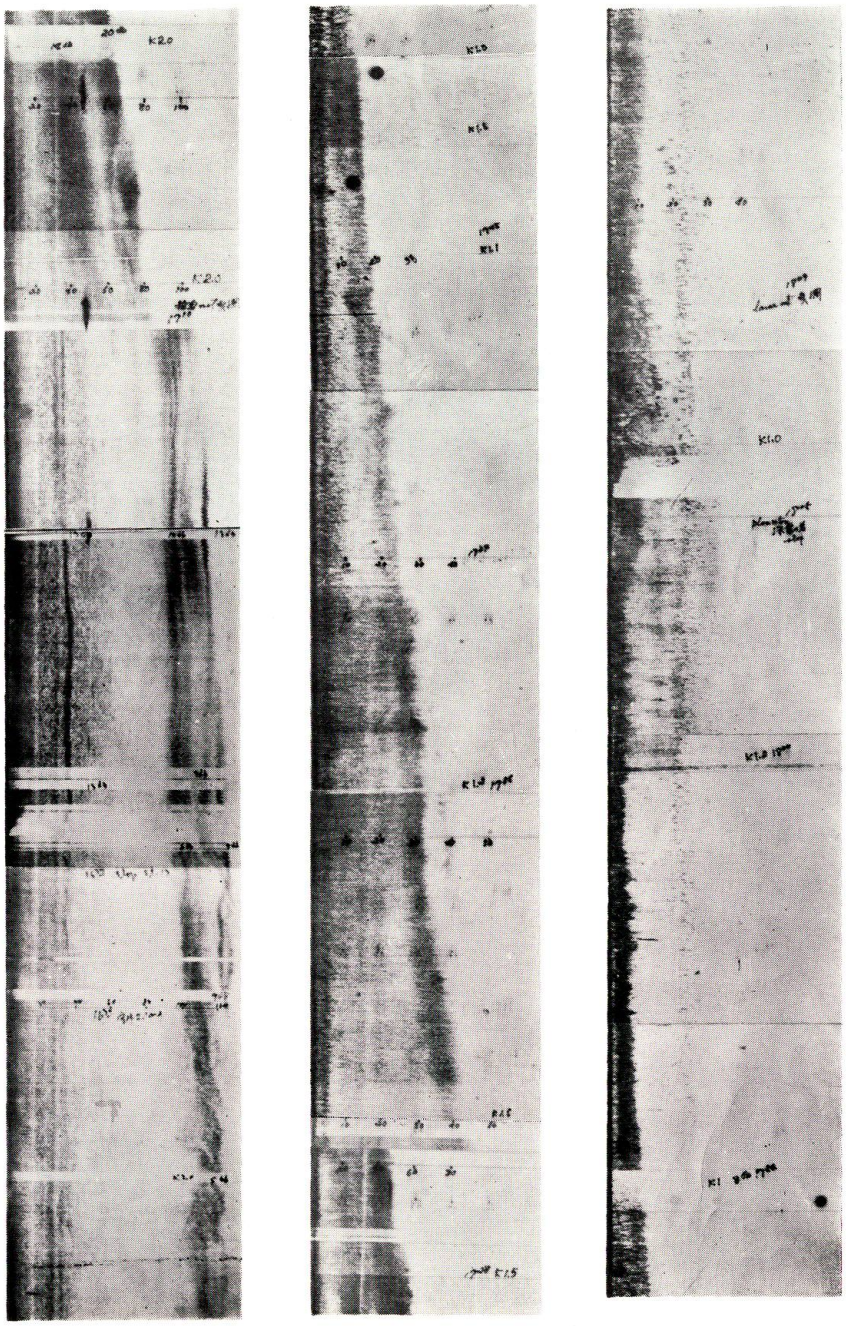


Fig. 32. Echo-image of DSL in the sea adjacent to Cape Erimo in August 1960 (DSL is rising)

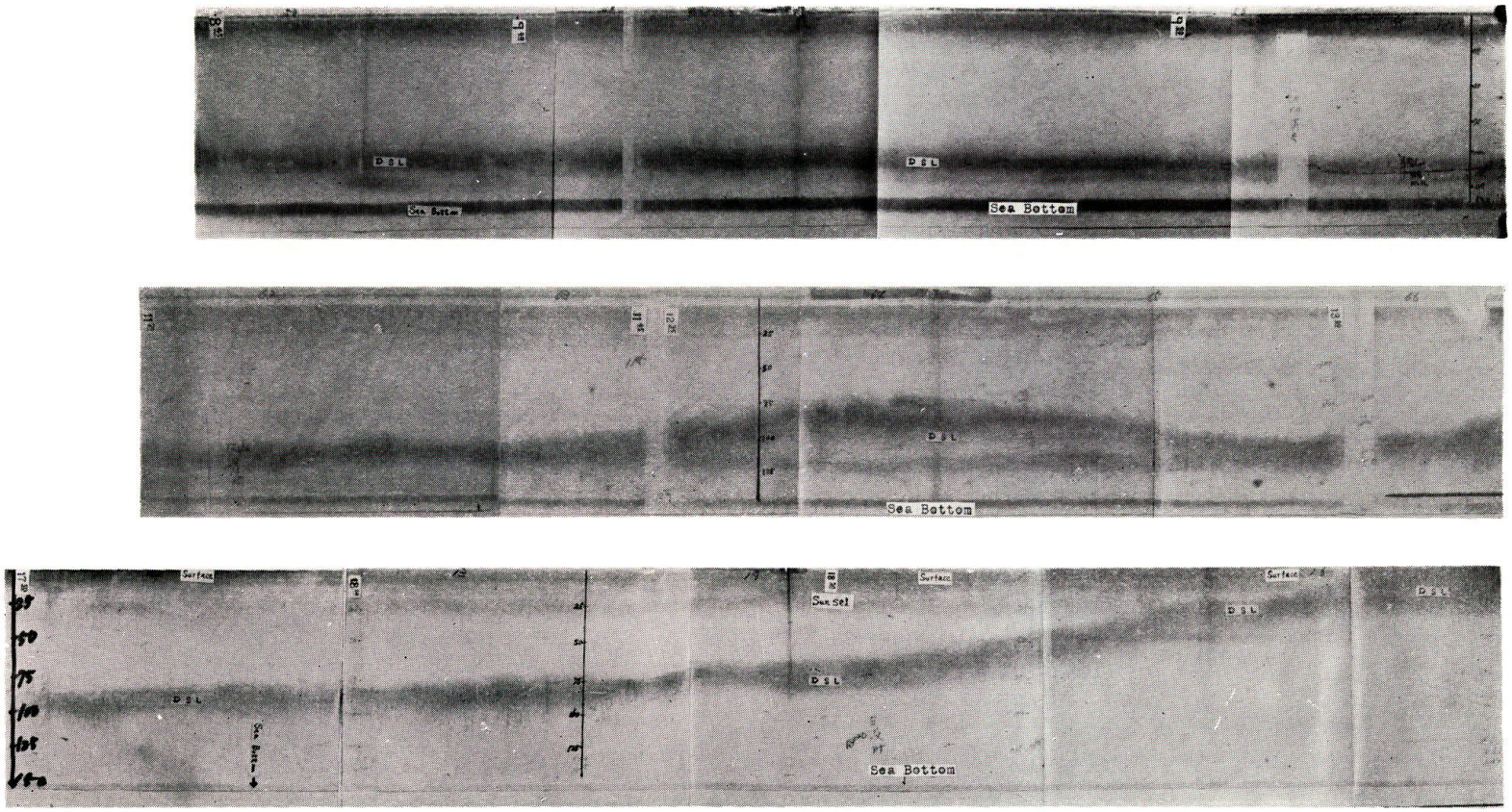


Fig. 33. Echo-image of DSL in the hours 8.00–19.00 in the sea adjacent to Cape Erimo in August 1961

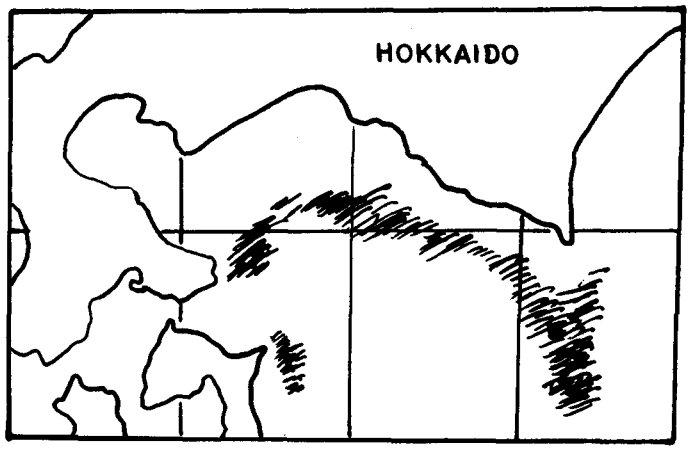


Fig. 34. Distribution of DSL in southeastern waters off Hokkaido

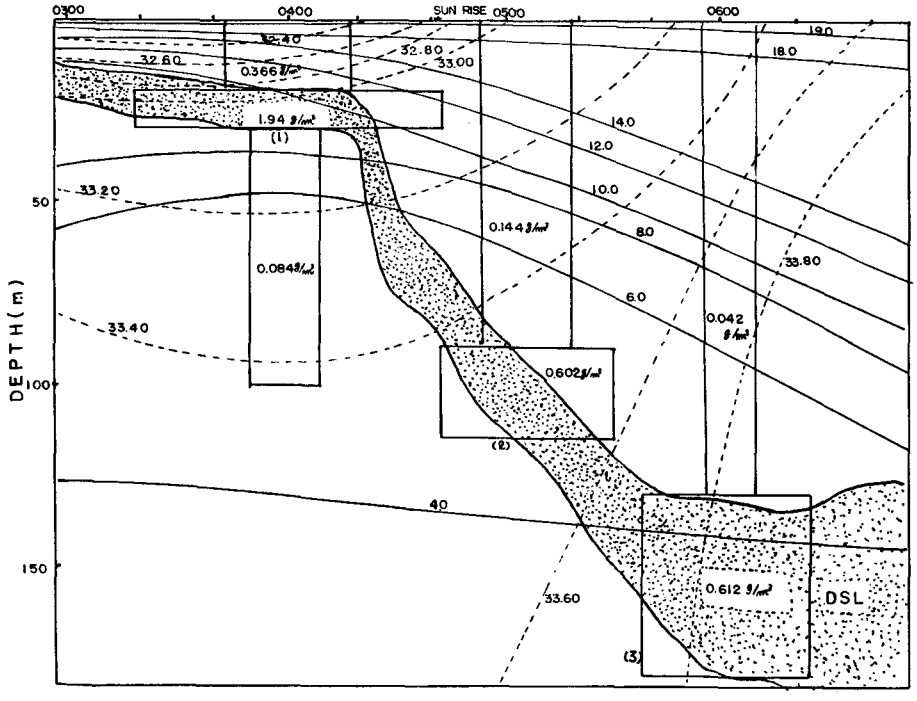


Fig. 35. Chart showing the relationship between DSL raised in the sea adjacent to Cape Erimo in August 1960 and the oceanographic conditions, and quantities of planktons (DSL is sinking)

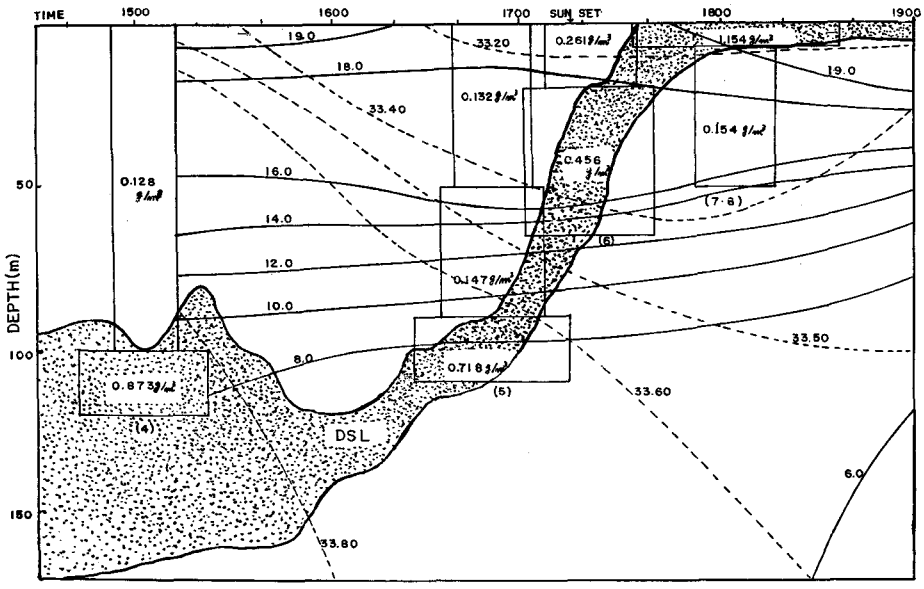


Fig. 36. Chart showing the relationship between DSL raised in the sea adjacent to Cape Erimo in August 1960 and the oceanographic conditions, and quantities of plankton (DSL is rising)

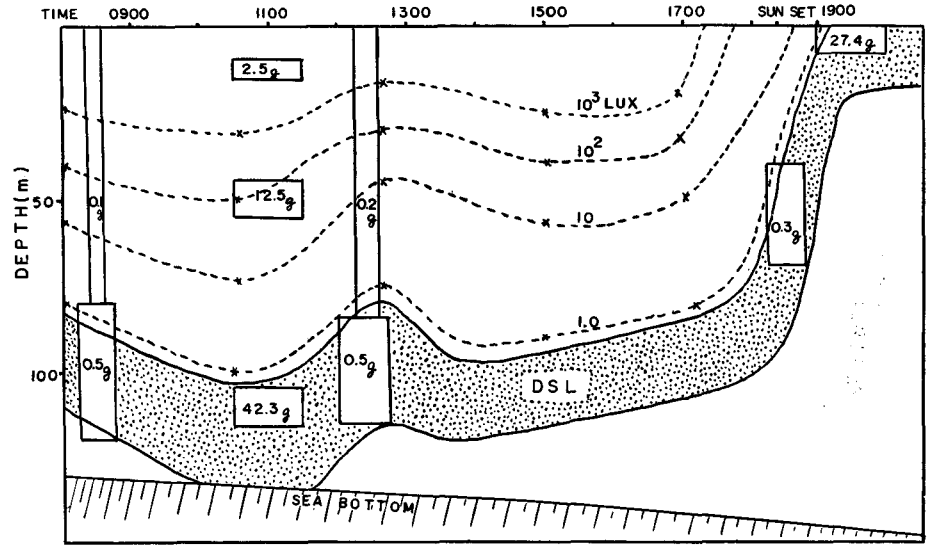


Fig. 37. Chart showing the relationship between DSL in the sea adjacent to Cape Erimo in August 1961 and submarine illumination

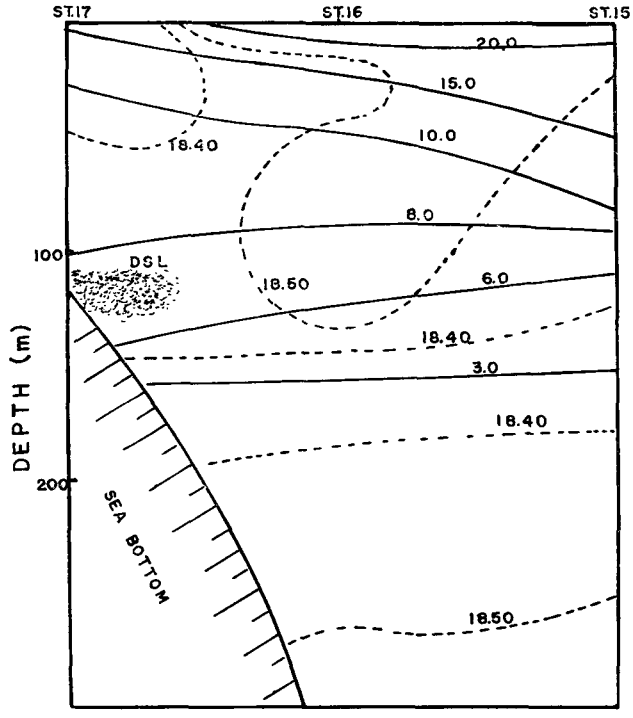


Fig. 38. Indicating the oceanographic conditions when the DSL was observed in the sea adjacent to Cape Erimo in August 1961

of squid from Oki Island, Shimane prefecture, resulting from ecological survey of squid seen there. Tauchi and Miyoshi (1939), on the basis of fishing conditions and variation in catches of squid, presumed a population of squid which makes large migration as *Sardinia melanosticta*, and some populations which make small local migrations. On the other hand, Soeda (1950), on the basis of (A) variation of fishing seasons and fishing grounds, (B) seasonal transition of surface water temperature 10°C and 17°C, (C) recapture of tagging release, and (D) measurement of mantle lengths of squid caught in various fishing grounds, concluded that there is only one type of squid living around Japan which makes a large migration from Kyushu to Saghalien. He mentions that the population which is migrating northward is caught in seas to the south of Hokkaido in July to August, called summer-squid by fishermen, while the population called autumn-squid migrating southward is caught abundantly in autumn.

Afterward, Soeda's report was questioned by several investigators such as Hoshino (1949), Mori (1949 and 1953), Tanaka and Iizuka (1956). They insist on two populations among squid living around Japan, one of which makes a large

Fig. 39. Planktons collected by larval net when the DSL rose to the water surface in the sea adjacent to Cape Erimo, October 1960

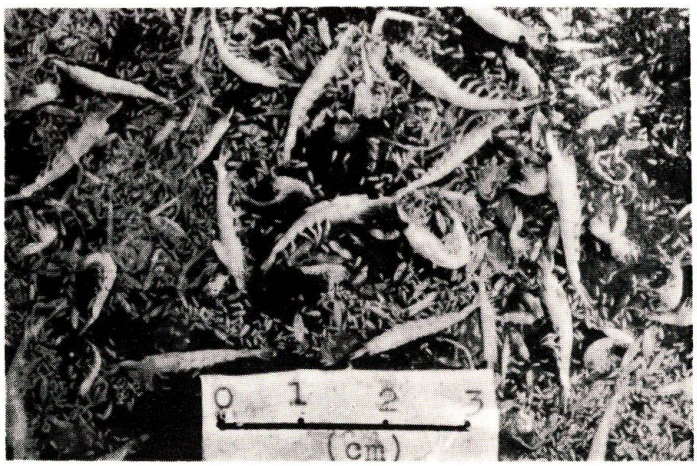


Fig. 40. Planktons collected by horizontal towing in DSL raised in the sea adjacent to Cape Erimo, August 1961

migration, whilst the other makes a small local one.

Araya, Otsuki and Machinaka (1958) and Fisheries Agency (1961) have carried on tagging release tests of squids since 1954, and they have assumed from the results of recaptures (Fig. 5) that the population of autumn squid in the sea to the south of Hokkaido and off the Sanriku district during mid-September and December, the end of the fishing season, is as follows: The stock of squids in these seas comprises only one population which migrates southward from the coast of eastern Hokkaido, and is broken up near Cape Erimo into two branches,

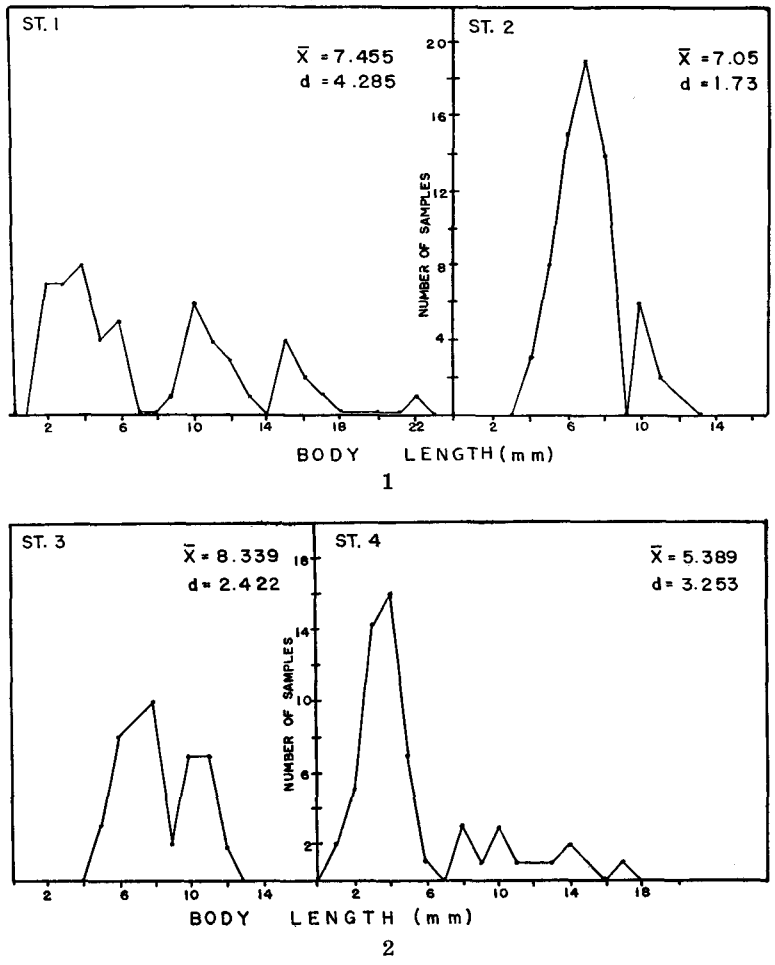


Fig. 41, 1–2. Body length composition of *Euphausia pacifica* collected from DSL in the sea adjacent to Cape Erimo, August 1960

one of which migrate west ward toward the Esan region while the others does toward the Sanriku district. Between those two branches no ecological differences were observed; they have referred the division to some environmental factors.

The writer agrees with the assumption by Araya *et al.* based on the transition of the major fishing season from eastern Hokkaido to southern Hokkaido and the Sanriku district, so he has tried to analyse the environmental factors which cause the variation in squid catch. As regards the environmental factors, data procured by the writer were those on the distribution of water temperature, salinity, and baits in these waters, therefore he has endeavoured to analyse them.

As squids migrate along the Oyashio coast such as in the sea off Nemuro and

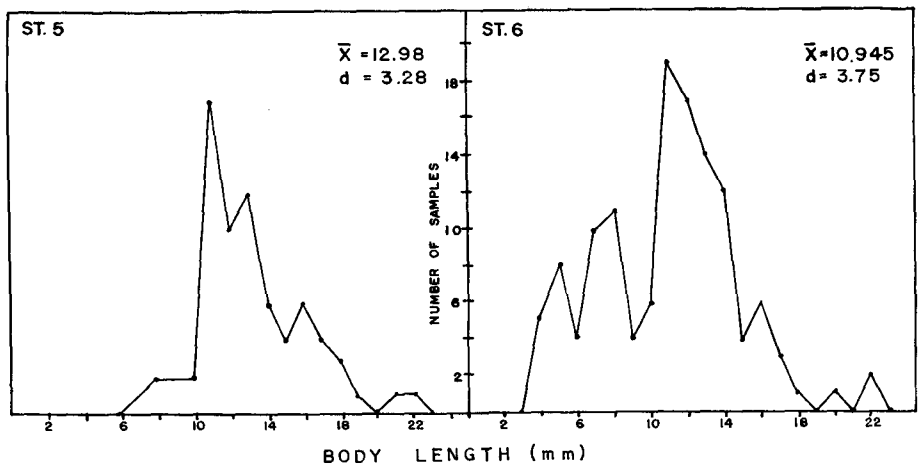


Fig. 41, 3-4. Body length composition of *Euphausia pacifica* collected from DSL in the sea adjacent to Cape Erimo, August 1960

Abashiri, and the Kuroshio coast in the Pacific, as well as along the coasts which are washed by the Tsushima and Tsugaru Warm Current, they are caught widely along the coasts of Japan. Consequently it is reasonable to understand them to be restricted to no certain water mass such as warm current or cold one, nor to

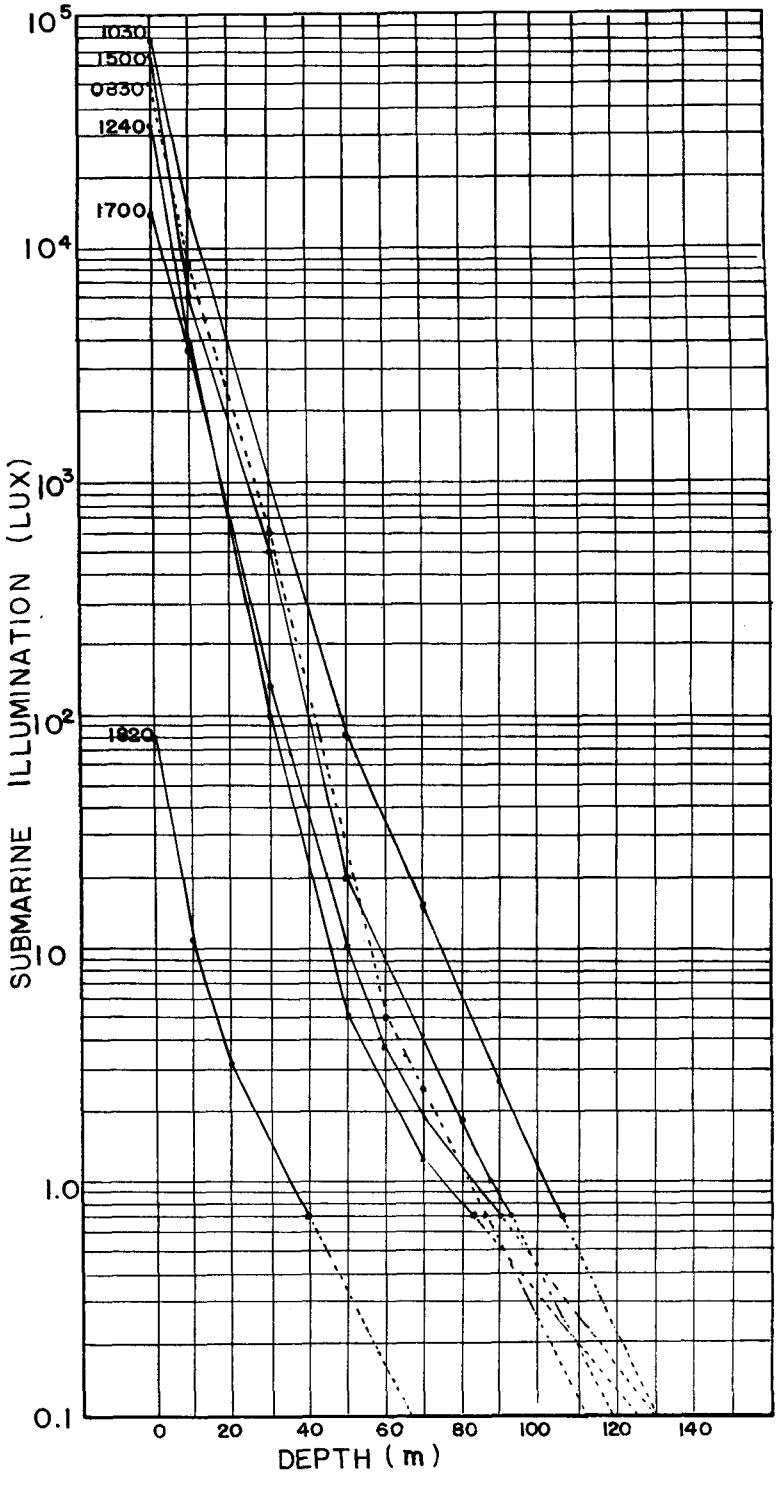


Fig. 42. Indicating the submarine illumination during the observation of DSL in the sea adjacent to Cape Erimo, August 1961

certain salinity.

There have appeared only a few reports on the optimum water temperature for squids. Sasaki (1921 and 1929) reports that in water at 10°C~17°C squids migrate in a thick shoal, thus water between those temperatures is suitable for fishing squids. Resulting from his survey of squid fishery near Oki Island, he has concluded that squids are caught most abundantly in a month in which water temperature continues at 15°C, and that the fact they swim gradually in a lower layer of water in daytime from spring to summer is in a good accordance with the sinking of water at 15°C. Furthermore he has stated that in a year when high water temperatures predominate and prevail to deep layer of sea, squid catch is scanty, whereas in a year when high water temperatures remain in surface layer of sea, their good catch results.

Uda (1942) reports that squids live in water between 5°C and 25°C, and optimum water temperature for fishing them is between 15°C and 16°C. Miyamoto (1935) observed in his fishing tests off Hakodate that they are caught abundantly in water shallower than 25 m at 12°C~24°C, and in water which is 40~60 m in depth at 10°C~18°C. Soeda (1950) mentions that major fishing seasons of squids along various coasts move in accordance with the transition of surface water temperature 17°C. Araya (1958) adds that the water layer, 10~25 m in depth, in which they were caught abundantly, showed 15°C~20°C in his fishing tests near Kojima Island, Hokkaido. The above findings are all fragmentary.

In the analysis of the correlation between the variation of CPUE to catchable stock of squid off southern Hokkaido and Sanriku district since 1954 and hydrographic conditions in seas southeast off Hokkaido, CPUE in Sanriku district exceeded that in seas off south Hokkaido in 1956, 1958 and 1960 as graphed from Fig. 9.

Hydrographic conditions observed in these years corresponded to those accompanying Stagnating type 2-Type B in which the Tsugaru Warm Current extended rather deeply to the coast of Hidaka Province except in 1960 when solitary warm water masses stayed for a long time at seas off south Kushiro. In every year since 1954 except the above mentioned three years, CPUE in the sea off southern Hokkaido exceeded that of Sanriku district; the extended forms of the Tsugaru Warm Current belonged to Type A, C or D.

Water temperature seen between Cape Erimo and the Tokachi Coast under hydrographic conditions belonging to Type B showed 15°C~12°C at the sea surface, and 8°C~4°C in the layer 100 m in depth (Figs. 17, 18, 43 and 44); water masses consisting of a shore branch of the Oyashio, and that seen in the

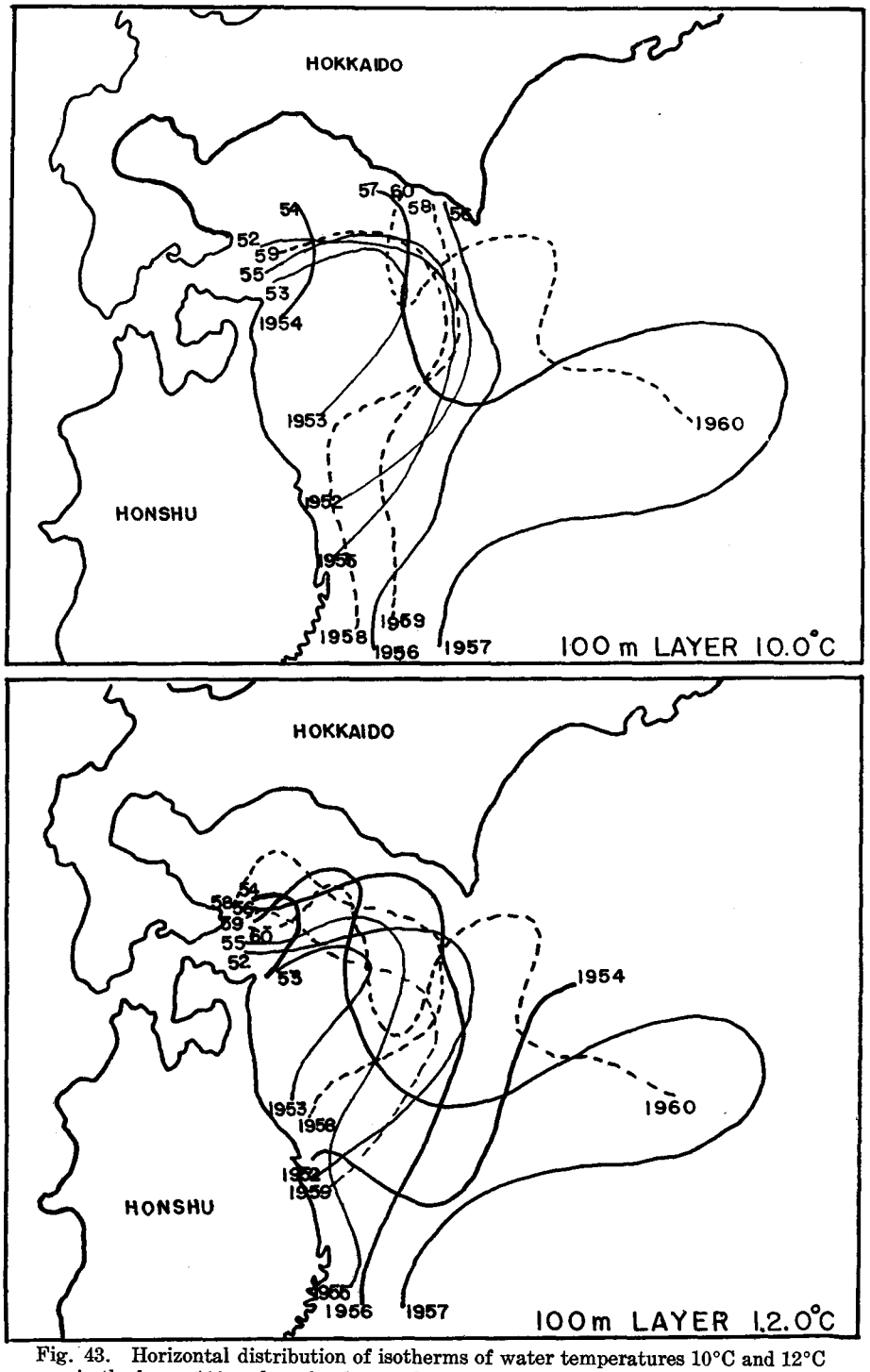


Fig. 43. Horizontal distribution of isotherms of water temperatures 10°C and 12°C in the layer 100 m deep in the southeastern waters of Hokkaido in November 1952–1960

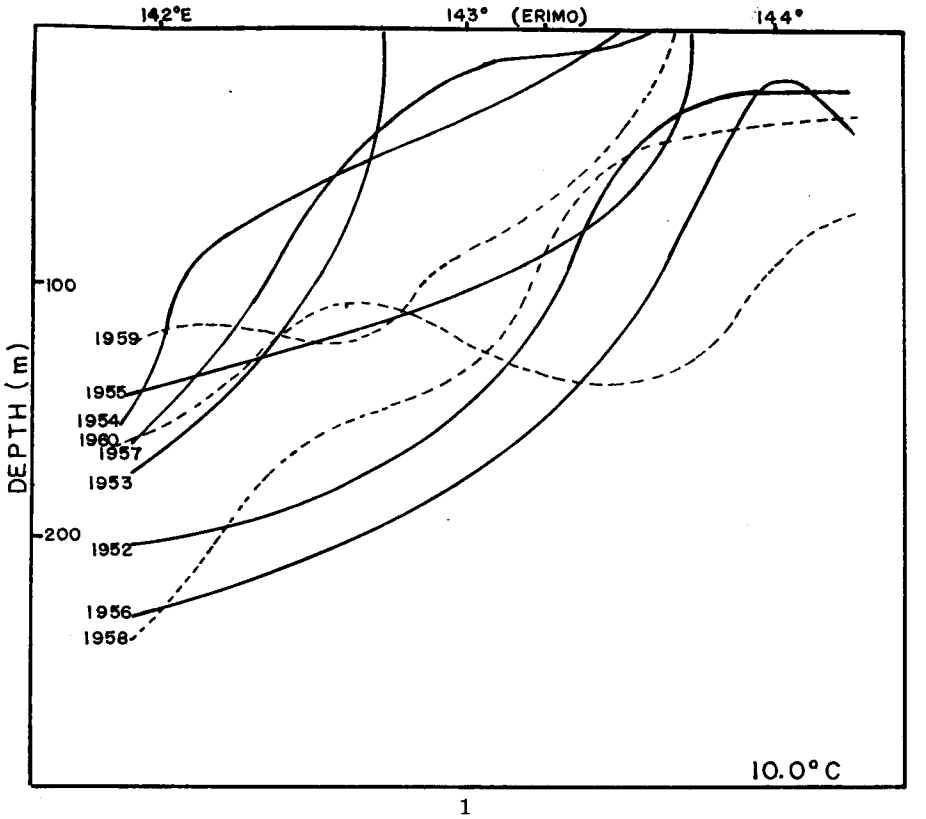


Fig. 44-1. Vertical distributions of isotherms of water temperatures 10°C and 12°C in the sea east off Cape Shiriya (Lat 41°-26′N) in November 1952-1960

sea westward from Cape Erimo showed 14°C~18°C in surface water, and 10°C~16°C in the layer, 100 m in depth; these were water masses belonging to the Tsugaru Warm Current. According to the statesments in the papers above listed, water temperature at about 15°C is suitable for fishing squids. If so, they should be migrating in abundance in the seas just mentioned to the south of Hokkaido. On the contrary, however, squid catches in the seas of the Sanriku district exceeded in quantity those in the sea to the south off Hokkaido. Prompt News on Fishing Conditions of Squid (1st news in 1956 by Hokkaido Regional Fisheries Research Laboratory), and Nishimura (1957) expressed the opinion that squid shoals migrated directly toward the Sanriku coast along the optimum water temperature zone in the boundary zones then constructed by the strong shore branch of the Oyashio between Cape Erimo and the Sanriku coast. It can not be explained only by knowledge till now on the suitable water temperature zones to say about 15°C~17°C for squid why the squid shoal migrated along the

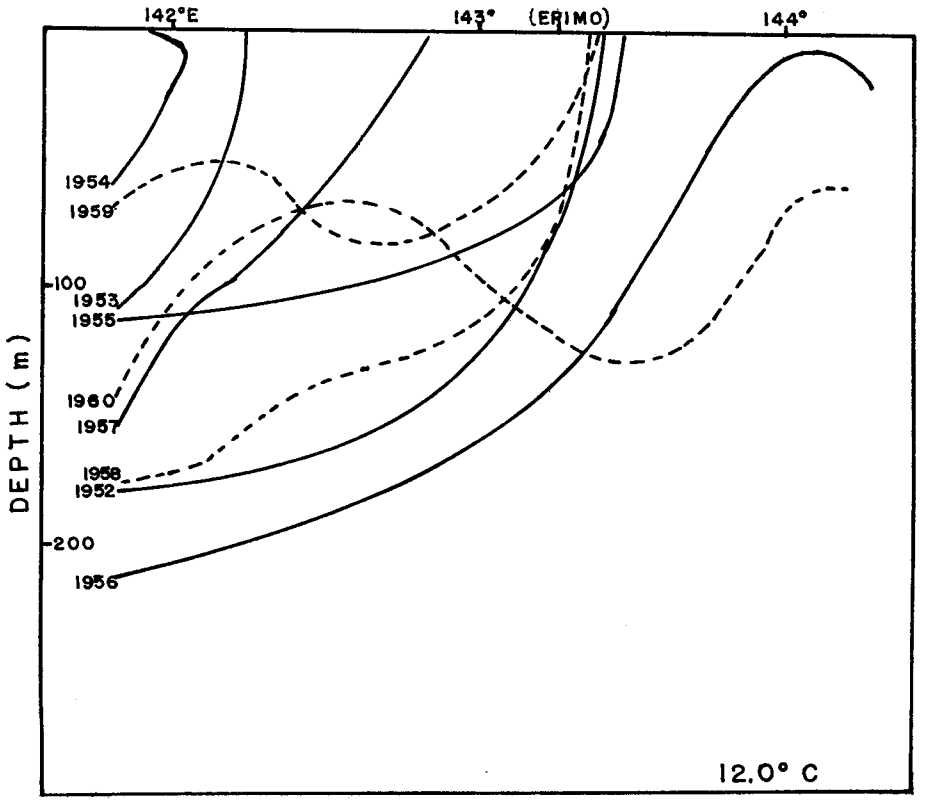


Fig. 44-2. Vertical distributions of isotherms of water temperatures 10°C and 12°C in the sea east off Cape Shiriya (Lat 41°-26′N) in November 1952–1960

boundary zones at low water temperature despite the location of optimum temperature water to the west of Cape Erimo, whilst only water temperature zones lower than 15°C were seen along Cape Erimo and the Kushiro and Tokachi Coasts where squid shoals actually migrated.

To make certain of the hydrographic conditions, careful investigation is needed of water temperature which is fit for squid, the optimum layer for its swimming and conditions of water during the creatures growth. However, there have appeared only a few reports on the depths at which it swims. As the animals are caught at 20~30 m from water surface at night, this layer of water is presumed empirically to be the favorite swimming layer of the animal. The former investigators have made this interpretation.

On the coast of Boshu province, and Sagami Bay, this animal is caught by means of line fishing at a depth of 100 m in the daytime. It is caught also pretty abundantly by small trawlers along various coasts. During World War II,

as the sea around Esan was designated as a fortified zone, no light was permitted to be used at night; then daylight squid fishing was introduced by fishermen in Boshu province, getting good catches (Takahashi, 1943; Tokuda, 1943).

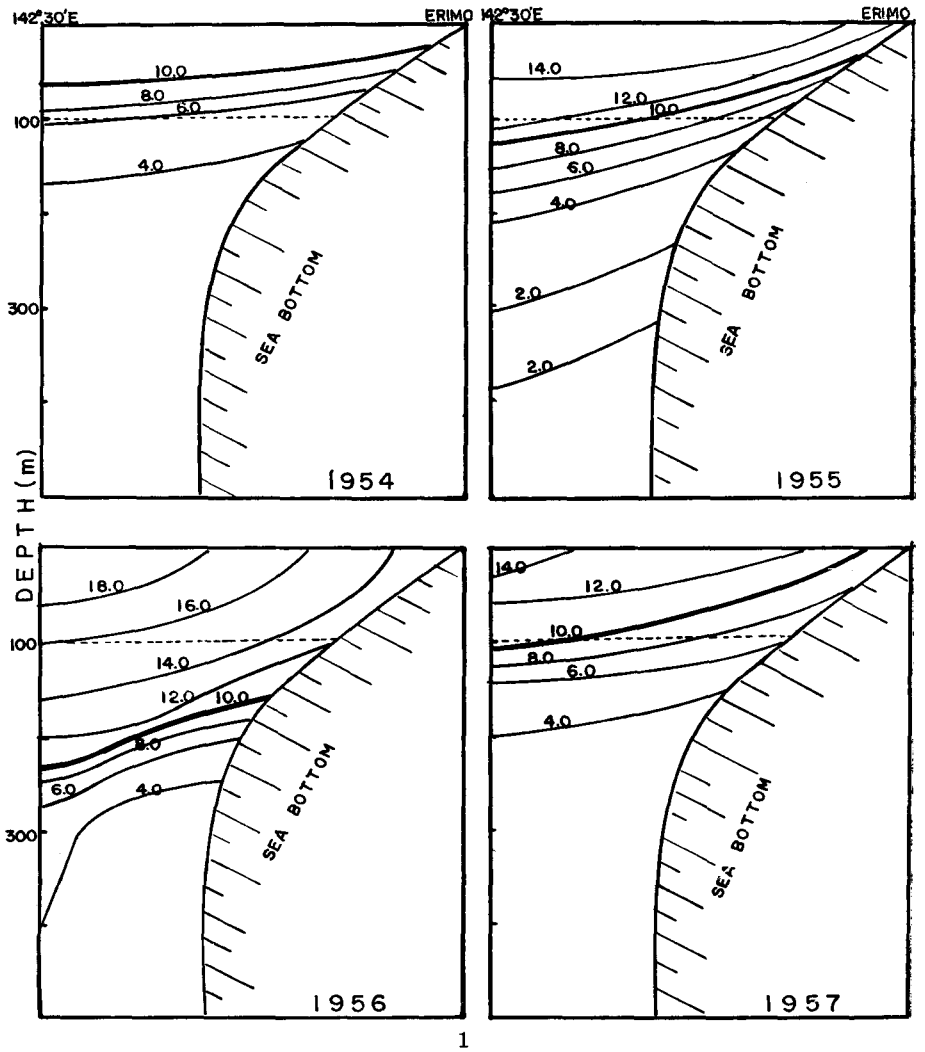
Uda (1956) reports that squid in Beppu Bay, Kyushu are seen at the bottom of the sea which is 70~80 m in depth, and in the evening with the rising of DSL. Isahaya (1931) likewise mentions that squid take baits in deep sea in the daytime, and come up to the surface at night.

Judging from these reports, the layer in which squid is caught at night is not the same as the one in which it is swimming in the daytime, consequently it may be said to be a superficial opinion that the water temperature at which it is caught is fitted to the line fishing of squid, or to make much of surface water temperature as a limiting factor in squid fishing.

As already mentioned above, hydrographic conditions in the seas off Southern Hokkaido in the year in which volume of CPUE in that locality is lower than that in the sea of the Sanriku district suggest condition attending Type B in which the Tsugaru Warm Current extends broadly and deeply. As regards the impeding factor involved in that type for the migration of squid toward the sea to the south of Hokkaido, the writer interprets as follows:

As known from the vertical distribution of water temperatures in Type B shown in Figs. 18 and 44, high water temperature zones above 10°C prevailed at that time from the 100 m layer to the 200 m layer. In horizontal distribution, also high water temperature zones above 10°C prevailed in the 100 m layer, from Cape Erimo to the coast of Hidaka (Figs. 17 and 43). No isotherm of 12°C reached as far as Cape Erimo or the coast of Hidaka as shown in Fig. 43. But, the 8°C isotherm reached to the eastern side of the cape, and between the two isotherm of 10°C. Fig. 45 shows the vertical distribution of water temperature between a point Lat. 41°-26′N, Long. 142°-30′E and Cape Erimo. As seen in the figure, high water temperature zones above 10°C distributed in shallow layer in the years except those belonging to Type B of 1956 and 1958. While, in the years when high water temperature distributed in deep layer (Type A), they did not reach to the coast of Hidaka. Instead, cold water masses entered this region moving west-ward from Cape Erimo.

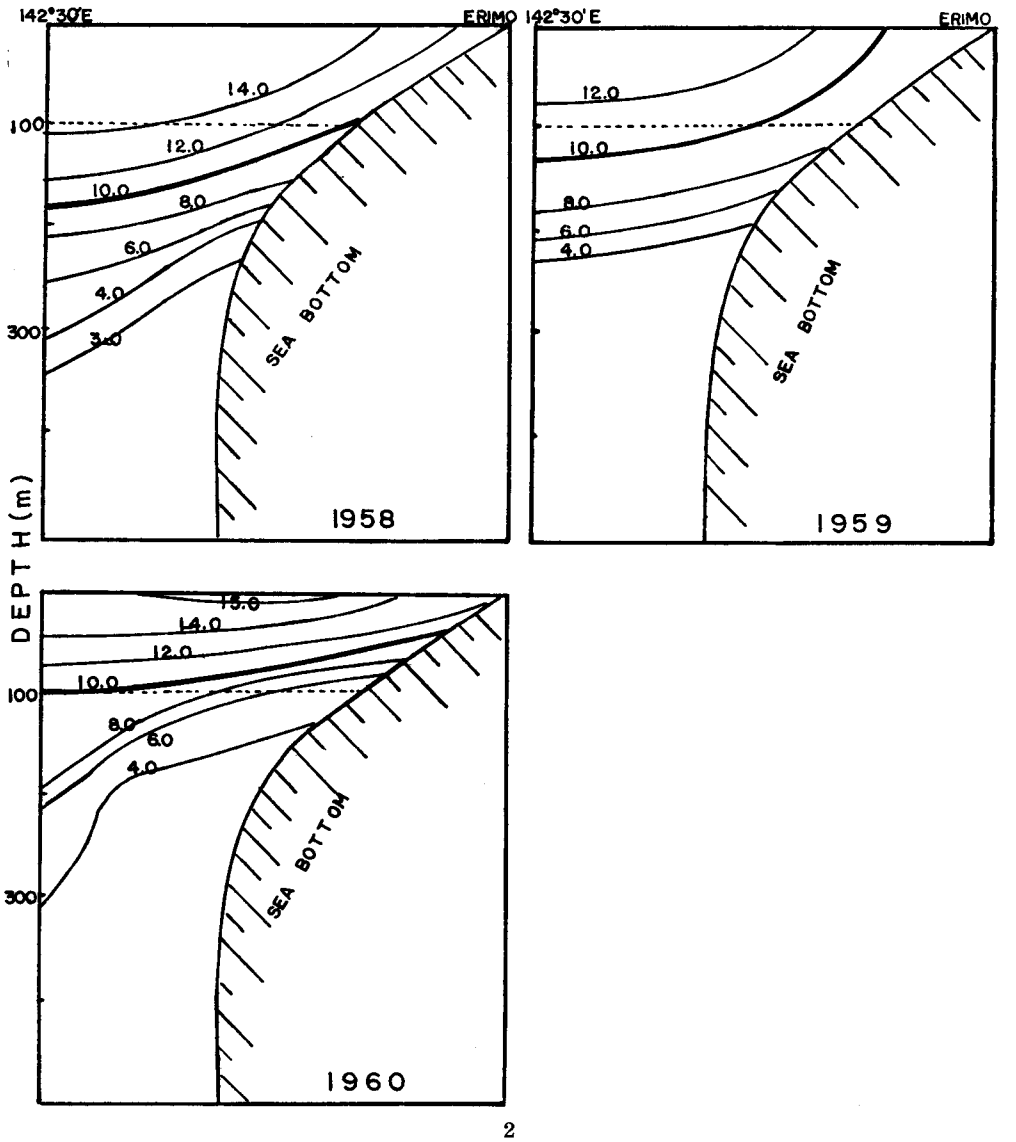
Concerning fishing conditions of squid Kawana and Isahaya (1928~1932) report, though not in a specifically form, that water temperatures of surface and mid-layer differ moderately at the time of good hauls of squid, decidely in case of usual hauls, and only slightly or not at all cases of poor or no hauls, Nagata (1957) mentions that cold water masses developed and marked upwelling was observed in major fishing season of squid when good hauls of summer squid



1

Fig. 45-1. Vertical section of water temperatures between the station Lat 41°-26′N, Long 142°-30′E and Cape Erimo in November 1954-1960

were seen on the eastern coast of San-in district, and in the case of poor hauls cold water masses disappeared and warm mid-layer water sank to the bottom. He points out in his observations on hydrography in years of good hauls, that cold water masses below 10°C upwelled above 100 m in depth. Miyamoto (1935) reports that cold upwelling water masses developed when catch per hook was large. Takehana (1951 and 1955) reports, on the basis of observations on the hydrography in 1950~1954, that in the vertical distribution of water temperatures between Esan, eastern entrance of the Tsugaru Straits, and Cape Shiriya,



2

Fig. 45-2. Vertical section of water temperatures between the station Lat 41°-26′N, Long 142°-30′E and Cape Erimo in November 1954-1960

when water masses below 10°C sank extremely deep, or oppressed toward Esan regional sea, squid catch was poor, and when water masses below 10°C developed it was good. Furthermore, Takehana continues, when water masses below 10°C grow in a small quantity, optimum temperature zone of water for squid is extended below mid-layer of water, therefore squid haul remains poor as the density

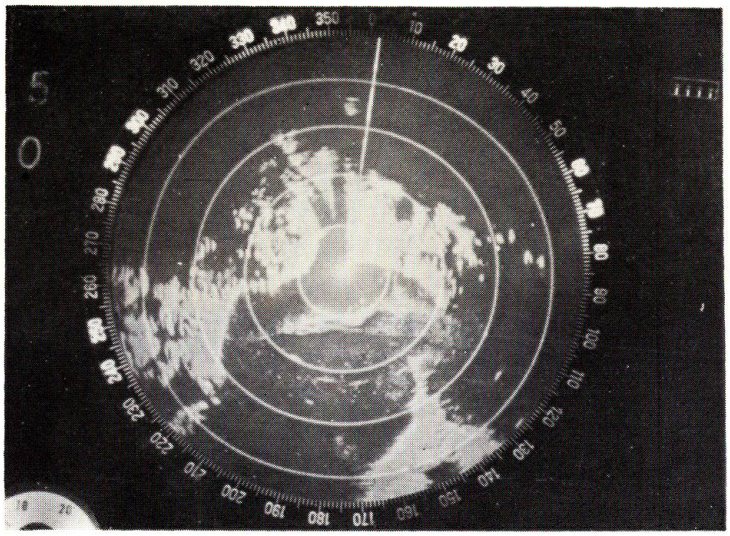
of the squid shoal becomes thin, and on the contrary, when water masses below 10°C develop, optimum temperature zone of water for squid is limited in area, thus inducing a good haul.

Putting together the statements of the authors mentioned above, one would conclude that the presence of a cold upwelling and the degree of its development decide squid catch. However, these statements are based on the assumption that water masses above 10°C are fit for the migration of squid.

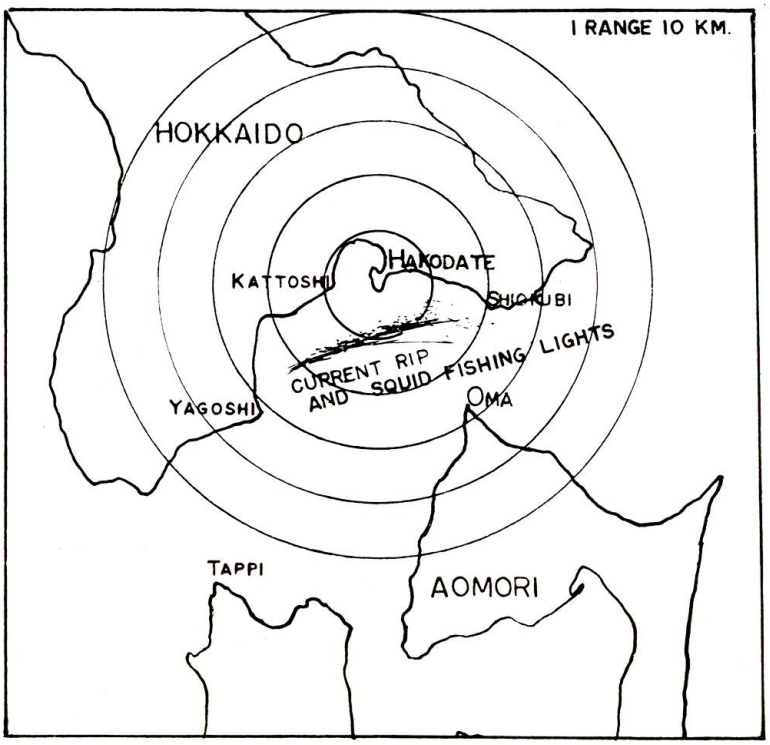
The main squid fishing grounds off southern Hokkaido in the Esan regional waters. On the reasons for this fact, Soeda (1956) interprets that as Esan regional water is washed by both the Tsugaru Warm Current and the Oyashio, it is very rich in baits, so ssuid migrate and stay in this water. According to the writer's field investigations and to the reports on the localities of squid fishing grounds presented by others, not the entire Esan regional waters form the main squid fishing grounds, but they have been restricted to the cold water masses side.

In the squid fish grounds off Hakodate, not the entire coasts of the Tsugaru Straits have formed the principal fishing grounds, but in the area to the outer northern side of the Tsugaru Warm Current, close to Hakodate, cold water masses have lain showing a distinct current rip, so that has formed the principal fishing grounds. In Fig. 46 are illustrated concentrated squid fishing lights and the distribution of current rips and fishing boats viewed through Mt. Hakodate Meteorological Radar. Off Shiranuka on the Shimokita Peninsula, Aomori prefecture, a good squid fishing ground is formed; it is called by fishermen a cemetery for squid. Takehana (1955) reports that released squids with taggings in this sea were almost all recaptured in the northern side of the Tsugaru Straits, or somewhere in the southern Japan Sea, as shown in Fig. 47. He offered no comments on this fact, except a statement of its being worth noticing. The writer in his field observation has verified a local upwelling of cold water masses off Shiranuka like that in Esan regional water (Fig. 25).

The phenomenon that squids migrate more abundantly toward the coasts of the Sanriku district than toward southern Hokkaido sea is considered to be due to the migration being impeded near Cape Erimo by high temperature water masses of the Tsugaru Warm Current. The reason why the size of squid catches are decided by cold water masses lying in deep layer is attributable to the impediment to floating up of squids by upper high temperature water masses rather than to oppression of swimming layer of squids by lower cold water masses. The facts that squid fishing grounds in Esan sea, off Hakodate, and Shiranuka are constructed in the sides of cold water masses, and that southward migration of squid shoals from Tokachi coast to southern Hokkaido sea and Sanriku sea are

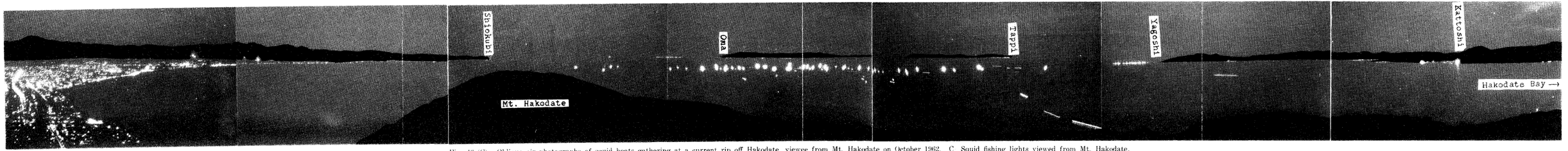


(A)



(B)

Fig. 46 (A and B). Oblique air photographs of squid boats gathering at a current rip off Hakodate, viewed from Mt. Hakodate on October 1962. A—Showing current rip and squid fishing boats, taken by meteological radar. B—Rough sketch of a current rip raised off Hakodate



(C)

Fig. 16 (C). Oblique air photographs of squid boats gathering at a current rip off Hakodate, viewee from Mt. Hakodate on October 1962. C Squid fishing lights viewed from Mt. Hakodate.

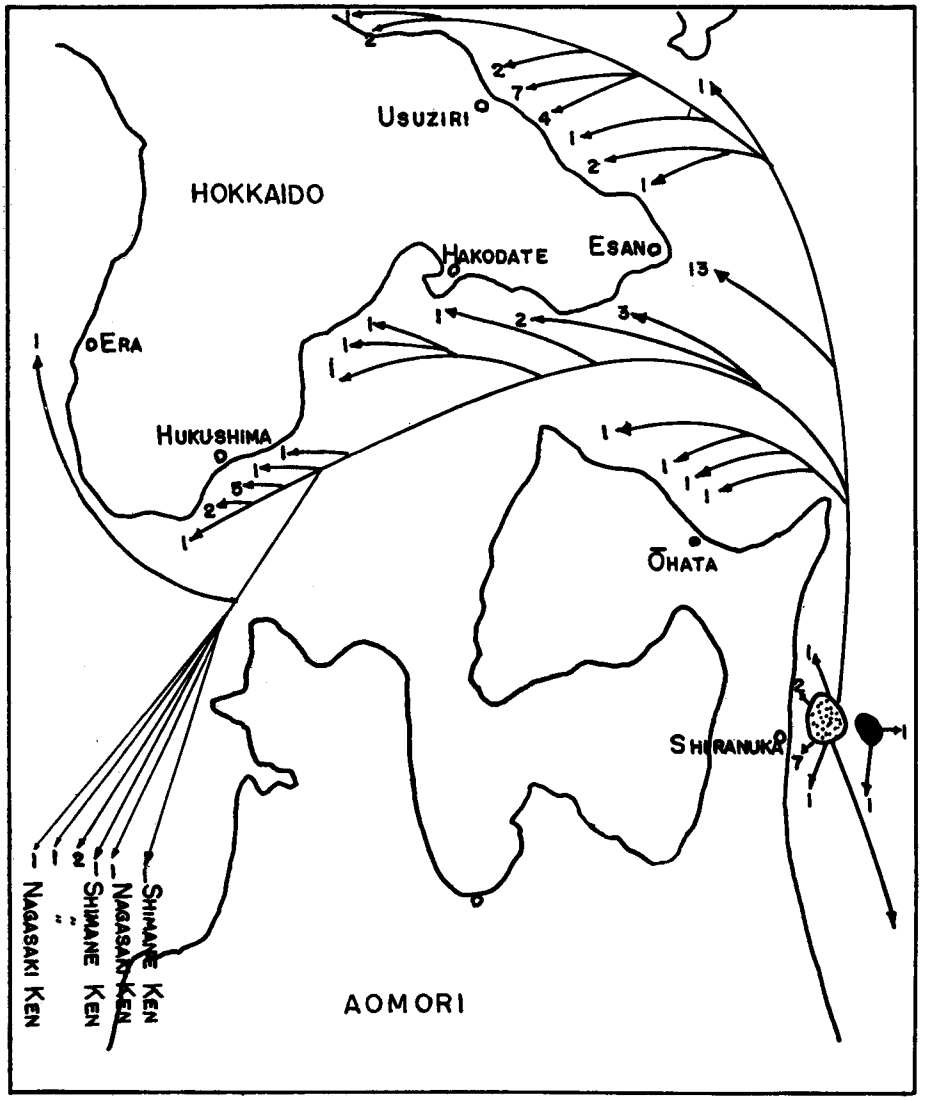


Fig. 47. Showing results obtained from the tagging release experiments off Shiranuka, Aomori Pref. on November 11, 1952

attributable to the explanation given above; it is assumed the optimum temperature water zones for squid migration are below 10°C when hydrographic condition belongs to Type B, and the animal swims in the layer at about 100 m depth, though the facts were inexplicable by explanations which have hitherto been presented by various authors.

As regards the recapture of tagged squids released off Shiranuka, it is to be

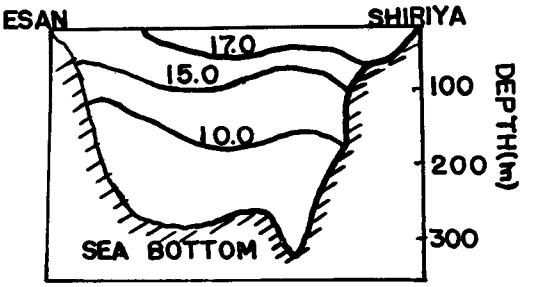


Fig. 48. Vertical distribution of water temperature between Esan and Cape Shiriya in November 1952

kept in mind that cold water masses below 10°C developed along the entire coast of both sides of the Tsugaru Straits as seen in Fig. 48; the squids released are considered to have migrated in the optimum temperature water under the Tsugaru Warm Current toward the cold water masses in the Esan area. As was pointed out by Soeda (1948), the fact that good squid fishing grounds lie in the Esan area is due to the squids long staying in this area for the sake of rich baits. His interpretation is also consonant with the distribution of DSL. In view of the physical hydrography, presence of optimum temperature water masses for squid in the side of cold Esan sea water masses in Esan area, and the prevention of flows of cold water masses into the Tsugaru Straits by eastward stream of the Tsugaru Warm Current, squids may reasonably by compelled to stay in the Esan area. A branch of the cold water masses penetrates into the northern region of the straits along the southern coasts of Hokkaido, forming a counter stream against the Tsugaru Warm Current. The flow becomes predominant during summer and autumn, and extends to 5~12 sea miles off Hakodate in the Straits (Nakayama and Takinami, 1961). Therefore squid shoals seen in the Esan area are presumed to have migrated westward in this cold water zone.

Squid migration and variation of population density in the seas off southern Hokkaido and the Sanriku district are described above; it may be concluded in connection with the hydrography as follows.

Squid shoals which come from Kushiro coast migrate toward Sanriku or southern Hokkaido, being impeded by warm water (above 10°C) in the Tsugaru Warm Current, swimming at about 100 m depth in the daytime.

As squid migrations, both northward and southward, belong to the feeding migration in immature stage (Soeda, 1950), bait seems to be one on the limiting factors of the migration. Sasaki (1921), Soeda (1950 and 1956), Isahaya (1930), Koga (1928) and Araya and Nakamichi (1962) report that baits of squid are small fishes including sardine and mackerel, some of their own species, and

crustacean planktons. According to six above named men, though the composition of baits varies with the time of collection, and circumstances under which squids live, crustacean planktons comprising mainly Amphipoda and Schizopoda are the commonest baits. Kawana (1929) reports that the quantity of stomach content is larger in squids caught in the evening than that in those caught in the morning, possibly due to baits taken in the daytime. Uda (1956) states that squids rise toward water surface in the fishing grounds in Beppu Bay with the rising of DSL in the evening.

The statement that DSL has a close relationship with the formation of fishing grounds has been supported by various investigators: by Nishimura (1958) on the small trawl fishing grounds in Eastern Chinese Sea, Hashimoto (1956) on the crab fishing grounds in Kamchatka and salmon and trout fishing grounds in the northern Pacific, Nishimura and Maniwa (1961) on the tuna fishing grounds in New Zealand and waters adjacent to the Philippines, Uda (1956) on shrimp (*Sergestes lucens* Hansen) fishing grounds in Suruga Bay, and squid fishing grounds in Beppu Bay, and Maeda (1957) on salmon and trout fishing grounds on the west coast of Kamchatka. As already stated in IV, 4, the above authors agree with each other in the view that DSL is mainly caused by planktons, and that DSL in the seas off southeastern Hokkaido is caused by crustacean planktons such as euphausiids.

As pointed out by Soeda (1950 and 1956) and Araya and Nakamichi (1962), the facts (A) that principal baits of squids which are caught to the southeast of Hokkaido consist of crustacean planktons, and (B) that DSL distributed in this region is caused mainly by crustacean planktons as euphausiids, seen to exert great influence upon the behavior of squid during the season of feeding migration.

The presumption that squids swim in a longer at about 100 m depth in the daytime may be strengthened supported by the following two facts: they feed much more in the daytime than at night, and planktons taken by them as baits are known to swim in the layer, 100~150 m in depth, as viewed from the vertical position of DSL. The squids are caught in the 20~30 m layer at night. This fact agrees well with the report by Uda (1956) that squids come up with the rising of DSL toward evening, suggesting a close correlation between DSL and squid fishing grounds.

Distribution of DSL to the side of the cold water masses at the outer margin of the extended Tsugaru Warm Current as well as water temeprature may control the squid stay in the Esan vicinity. In the hydrographic condition classified into Type B in which the Tsugaru Warm Current extends broadly, DSL is distributed

continuously from Cape Erimo to the Sanriku coast, but it is impeded by the Tsugaru Warm Current, from extending to Esan. So if the squid migration is decided by baits only, the creature will migrate toward Sanriku coast in case of Type B hydrographic condition.

Regarding the reason why crustacean planktons such as euphausiids swarm in the side of cold water masses in the outer margin of the Tsugaru Warm Current is unknown, but Komaki and Matsue (1958) remark that they swarm naturally in the outer margin of the Tsushima Warm Current, or in the water where upwellings develop. As reported by Boden (1955) they are distributed originally in abundance in the subarctic zones in the Pacific. In short, they belong to a cold water species, so they may reasonably swarm in the boundary zones where cold water masses meet warm water masses.

Regarding the relationship between the living layer of Euphausiacea and its illumination, Waterman (1939) observed in the ocean light enough to stimulate the eyes of crustacea in the layer of 600 fathoms depth in the daytime; Moore (1950) found two forms of crustacea, one of which lives in the daytime in layers shallower than 100 fathoms depth, and the other in deep layers at about 300 fathoms. The form living in shallow water floats in the surface layer of water at night, while the one living in deep water rises to layers at 150 fathoms depth. The latter form is larger in size than the former, and begins sinking promptly at 100~200 feet/min. at illumination 10^{-8} lux in the daytime, stopping at about 10^{-12} lux.

Euphausia pacifica seen in the sea southeast off Hokkaido seem to live in layers at 100~150 m depth in the daytime as viewed from the position of DSL, and they float in the surface layer at night. DSL has been observed parallel to the layer of isolumes within the range of 0.1~1.0 lux. Velocity in the rising and floating of this plankton has been in accord with that variation of submarine illumination, showing ca. 1.5~0.5 m/min. Occasionally DSL has begun rising immediately with the decrease of submarine illumination owing to the sun having been obscured by clouds (Fig. 39).

Moore (1950) points out that rising and sinking of Euphausiacea may be impeded by a certain thermal condition. However, the writer could observe no such phenomenon as that in water at 5°C~20°C.

As described above in detail, the writer believes he has been able to elucidate the distribution of crustacean planktons such as euphausiid and their biological behavior in seas southeast off Hokkaido, and to elucidate the condition of the extended Tsugaru Warm Current which decides the southward migration of squids. Accordingly, to forecast squid fishing conditions in the sea to the south

of Hokkaido and off the Sanriku coasts, it is most helpful to investigate to which streaming type the Tsugaru Warm Current belongs among the four types A, B, C and D, as the population density of squids to be caught in southern Hokkaido seas is smaller than in the sea of Sanriku seas in case of Type B. The simplest method for such investigation is to observe whether water zones above 10°C develop in layer deeper than 100 m and along shore near beaches in vertical observatoin on hydrography between the place at Lat. 41°-26′N and Long. 142°-30′E and Cape Erimo covering ca. 45 sea miles in distance. By this method, one can judge the character of the Tsugaru Warm Current whether its streaming type is A, B, C or D. The extended shape of the current may be known from the distribution of current rips as viewed from an airplane. On the other hand, as DSL formed in seas southeast off Hokkaido is distributed on the side of cold water masses outside the extension of the Tsugaru Warm Current, the rough situation of boundary waters and extended shape of the current can be ascertained by the position of DSL near Cape Erimo.

VI. Consideration and Summary

6. 1. Consideration

The writer has clarified in the present studies the correlations between squid migration in seas southeast off Hokkaido, and hydrographic conditions and formation of DSL.

Judging from the deductions based on recaptures of tagging release tests of squids since 1954, squid shoals migrating southward from the sea near Kushiro and Tokachi (Provinces) are divided into two groups near Cape Erimo, one migrating toward the Sanriku coasts, and the other more westerly toward southern Hokkaido sea areas. As to whether the squid groups migrating southward belong to one and the same population which divides into two as mentioned above, or whether they belong to heterogeneous populations which divide into two near Cape Erimo, ecological and biological studies have hitherto been carried out by various investigators. According to them, these two groups which migrate toward southern Hokkaido seas and Sanriku seas are supposed not to be heterogeneous, but to be homogeneous.

The writer has studied the water temperatures (current) and DSL around these regional seas and also (baits) having it is mind that this division may be induced by environmental fatcors.

First of all, analysis was made of hydrographic conditions in the seas of

southern Hokkaido, Sanriku, and eastern Hokkaido, employing data since 1954 to 1960 published in Agriculture, Forestry and Fishing Statistics Monthly, annual Report of Catch Statistics of Fishery and Agriculture, interim statistics on catches compiled by offices in Kitami, Obihiro, Hakodate, Aomori, Iwate and Miyagi, Statistics and Survey Division of the same ministry.

CPUE in seas south off Hokkaido in 1956, 1958 and 1960 proved to be smaller than that in Sanriku seas from the results of the analyses mentioned above. To clarify the cause of this fact, study was made of hydrographic conditions in southeastern Hokkaido seas basis of in "Kaiyo-sokuho" or Prompt Reports No. 36~78 on Hydrography issued by Hakodate Marine Observatory. The hydrographic conditions may be classified into four types, Type A (Stagnating type 1), B (Stagnating type 2), C (Flowing southward type 1) and D (Flowing southward type 2). Hydrographic conditions showed to be Type B in the years when CPUE in the seas of southern Hokkaido was lower than that in the seas of the Sanriku district. In Type B, extended range of the Tsugaru Warm Current was very broad extending to the Hidaka coast. The water masses just mentioned stay in this water region gradually increasing their depth; water masses above 10°C extend deeper than 200 m in November or so.

Study was made of relationship between migrations and vertical movements of squids and formation of DSL. DSL proved to be distributed on the side of the cold water masses near the boundary zones at the outer margin of the extended Tsugaru Warm Current, and to consist mainly of such crustacean zooplanktons as *Euphausia* and *Parathemisto*. These planktons are distributed in layers at 100~150 m depth in the daytime, and make such diurnal vertical movement as rising toward evening and sinking before daybreak. Distribution layer of these planktons vertically moves parallel to the submarine isolumes level at 0.2~1.0 lux at the same velocity as the vertical movement of submarine illumination, showing 1.7~0.5 m/min. Baits of squids consist of small fishes, and crustacean planktons, there is some cannibalism. They feed more in the daytime than at night, and it is presumed that they would feed in the deep place of the sea, as crustacean planktons are found in abundance in the intestines of squids caught toward evening. Accordingly squids are presumed to live in the daytime in DSL in which their baits are distributed abundantly.

It is likewisely presumed that squid migration may be discouraged by water masses above 10°C; the optimum water temperature for its existence is 10.0°C~4.0°C as considered from the hydrography of Type B; the creature will swim in the daytime in water at about 100 m depth as viewed from the distributions of water temperature and baits.

It may be necessary in the first place to survey the extended shape of the Tsugaru Warm Current in order in the seas off southern Hokkaido and Sanriku to forecast the relative population densities of squid shoals, which have migrated south from Kushiro toward these two areas. To know the extended shape of the current, it is the most expeditions way to survey the situation of boundary zones of water, which by the distribution of DSL, though observations from an airplane may be most convenient. In case of hydrographical observations, the extended shape of the current may be roughly known by observation on the vertical distribution of water masses as 10°C between Lat. 41°-26′N, Long. 142°-30′E and Cape Erimo covering a distance of about 45 sea miles.

6. 2. Summary

The present studies deal with the relationship between the fishing conditions for squids which are one of the important fisheries resources in shore waters of Japan and the hydrographic conditions and the formation of DSL in south-eastern sea of Hokkaido. The results obtained from these studies are summarized as follows:

1. Data on the hydrographic conditions in the years 1950~1960 were based on those published by Hakodate Marine Observatory, and those for 1960~1961 were based on the writers own observations. Statistics on squid catches in the years 1952~1960 were based on those in the annual reports of catch statistics, Ministry of Agriculture and Forestry, and on those in the interim reports of catch statistics, produced by offices in Hakodate, Obihiro, Aomori, Iwate, and Miyagi, statistics and Survey Division of the same ministry. Observations on DSL and Current rips were made from airplanes in 1960~1961.

2. In Japan the total annual catches of squid attain to 6~14% of total annual catches of all sorts of aquatic animals, and to ca. 90% of those of all species of cuttlefishes. Squid catches from Hokkaido attain to 50% of those from all Japan, and those from southern waters off Hokkaido attain to 40~60% of those from all Hokkaido.

3. Annual catches of squid have remarkably increased in amount since World War II, showing 6×10^5 tons in 1952, then gradually decreasing to 3×10^5 tons in 1956, and finally increasing again to 48×10^4 tons in 1960. This remarkable increase since the World War II is due to the improved fishing gears and increase in numbers of fishing boats.

4. CPUE for squids migrating southward showed 2.85 tons in 1954, and 3.45 tons in 1955 in the seas off southern Hokkaido. In the seas of the Sanriku district it showed 1.11 tons in 1954 and 2.13 tons in 1955. After that year it

showed 1.25 tons, 1.73 tons, 1.14 tons, 2.20 tons and 1.61 tons respectively between 1956 and 1960 in the seas off southern Hokkaido, while in the Sanriku seas it showed 2.29 tons, 1.62 tons, 1.87 tons, 1.58 tons, and 2.00 tons during those years, thus showing alternate increase and decrease by years. Annual variations of the ratio of CPUE in eastern Hokkaido seas to that in southern Hokkaido and Sanriku seas have always corresponded. This proves that population densities of squids to be caught in the seas of southern Hokkaido and Sanriku district have a strong correlation with those in eastern Hokkaido seas.

5. Annual effective fishing effort showed higher value in the years after 1957 in which squid fishing boats had moved to eastern Hokkaido seas where larger CPUE was obtained than in the years before 1956 when the boats gathered mainly in the seas of southern Hokkaido.

6. Squid shoals which migrate southward from eastern Hokkaido seas are divided into two groups near Cape Erimo, one migrates on toward southern Hokkaido, and the other toward the Sanriku district; the division is probably caused by some limiting factors, but not by any inherent heterogeneity.

7. Streaming types of the Tsugaru Warm Current in southeastern sea of Hokkaido are classified into four types, Type A (stagnating type 1), B (stagnating type 2), C (flowing southward type 1) and D (flowing southward type 2).

8. In the year in which the hydrographic conditions show Type B, CPUE in southern Hokkaido seas is smaller than that in the seas of the Sanriku district. Judging from hydrographic conditions, the optimum water temperature for squid migration seems to be 10°C~4.0°C.

9. DSL is distinctly formed near the extended outer margin of the Tsugaru Warm Current on the side of cold water masses which have originated from the Oyashio. It consists mainly of crustacean planktons like euphausiid which are suitable for the baits of squid.

10. DSL is raised in the daytime in the layers at 100~150 m depth. Its diurnal vertical movement is made in accordance with the isolumes level at 0.1~1.0 lux at 1.7~0.5 m/min. in velocity as measured by the writer in proportion to the vertical movement of the submarine illumination.

11. Swimming layer of squids in the daytime is reasonably presumed to be at ca. 100 m depth judging from the extended shape of the Tsugaru Warm Current, depth of DSL from water surface in the daytime, and water temperature by which migrations of squids are impeded.

12. Distinct current rips are caused in the seas to the southeast off by the impact between cold water masses near Esan and the Tsugaru Warm Current, and by another meeting between the Tsugaru Warm Current near Cape Erimo

and a shore branch of the Oyashio.

13. The relative population densities of squids to be caught in the seas of southern Hokkaido and Sanriku district may be forecasted by the streaming types of the Tsugaru Warm Current; these types can be known by the situation of boundary zones of water.

14. It is most convenient to make observations from an airplane in boundary zones of water; it is also possible to know the situation of the latter by the formation of DSL. In observations on hydrography, observations on the vertical distribution of water temperature should be necessary at least covering the distance of 45 sea miles between Lat. 41°-26′N, Long. 142°-30′E, which is attribution of water masses as 10°C between Lat. 41°-26′N, Long. 142°-30′E and the east of Cape Shiriya and Cape Erimo.

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