SUBARCTIC OCEANOGRAPHY IN RELATION TO WHALING AND SALMON FISHERIES

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INTRODUCTION

Since the year 1952 after the World War II the Japanese High Sea Whaling and Salmon Fisheries were again undertaken with the oceanographic surveys every year and particularly since the NORPAC Project in 1955 the oceanographic surveys covering the whole areas of Subarctic North Pacific Waters from west to east were carried out during the years of 1955–1960.

The present paper is a summary of oceanographic structure in the subarctic waters of North Pacific Ocean (Uda, 1960, 1962) and the results of studies concerning hydrographic conditions in relation to the Whaling and Salmon Fisheries with the purpose to give some useful prediction indices for them.

SUBMARINE TOPOGRAPHY IN RELATION TO WHALING GROUNDS

The shaded steepest zone of continental slope is shown in Fig. 1 which

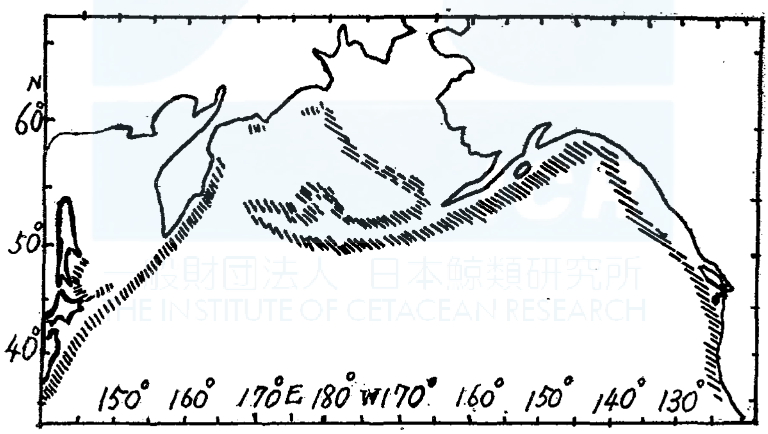

Fig. 1. Zone of maximum bathymetric gradient

corresponds to the counterclockwise circulatory migration route of whales and consequently contributes to some of the favourable whaling grounds.

Localities of maximum curvature of isobathymetrical lines (Fleming,

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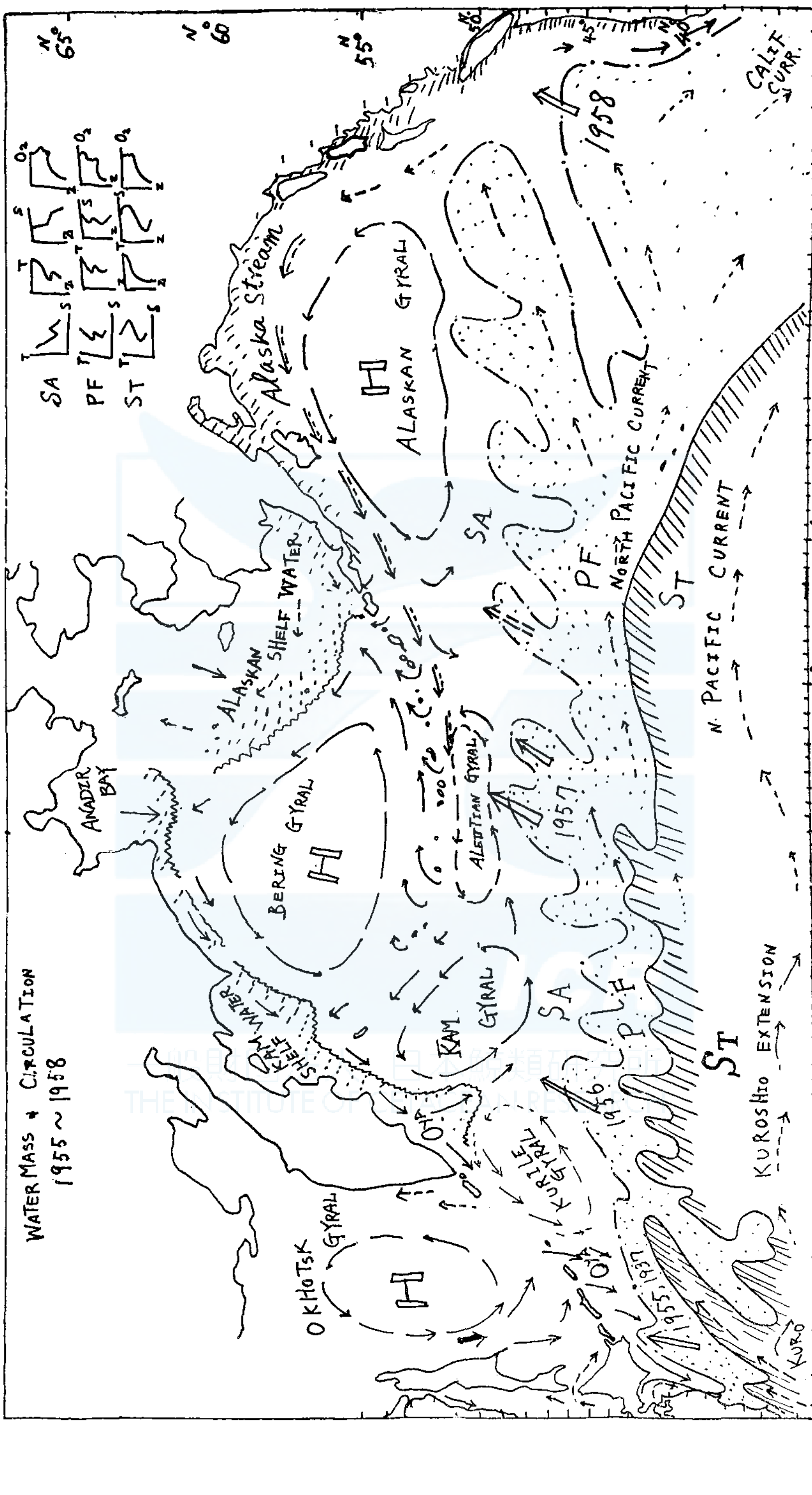

Fig. 2. Schematic map of watermasses and circulation in the Subarctic Pacific (1955–'58).

1955) appear to correspond to the particulary favourable whaling grounds α, β, γ, δ as shown in Figs. 2, 3 compared to Fig. 1., probably due to the concentration of whales and abundant food organisms.

CURRENTS AND WATERMASSES IN RELATION TO WHALING AND SALMON FISHING GROUNDS

Analysis of available hydrographic data collected in the North Pacific (north to 30°N) down to the 1000 m. depth or more for the years 1955–'59, proved the principal three types of watermasses i. e. Subarctic, Polar Frontal (including three subtypes) and Subtropical watermasses with several characteristic gyres and currents as shown in Fig. 2.

The watermasses, gyres and circulations are corresponded to the distribution, migration and conjectured stocks of salmons and whales in general, as suggested by the results of tagging or marking experiments and fishing grounds as the results of fishing exploition.

1. The averaged pattern of *geostrophic circulation* during the years 1955–'59 is shown in Fig. 3, based on the dynamic topography for dynamic anomaly (0 db./1000 db.). The basic pattern referred to 500 db. or even 300 db. as reference level is roughly the same to the above in the Subarctic waters.

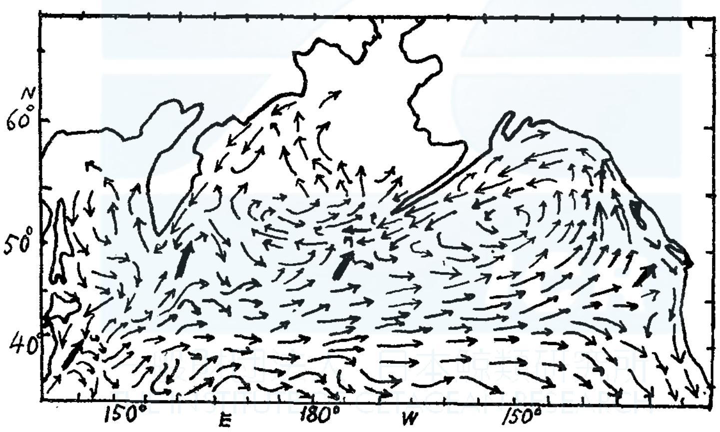

Fig. 3. Circulation based on geopotential topography. Summer (1955–'58) ΔD (0/1000 db.)

2. As a good indicator of Subarctic Watermass and a measure of winter temperature, the extent of *dichothermal water* (intercooled water, mainly produced in winter by convectional cooling and persists its trend to summer) with its core depth was studied (Fig. 4.). Salmon is very scarce in the domain of temperature less than 1–2°C and very abundant in the domain of 4–7°C near the frontal zone of dichothermal cold core

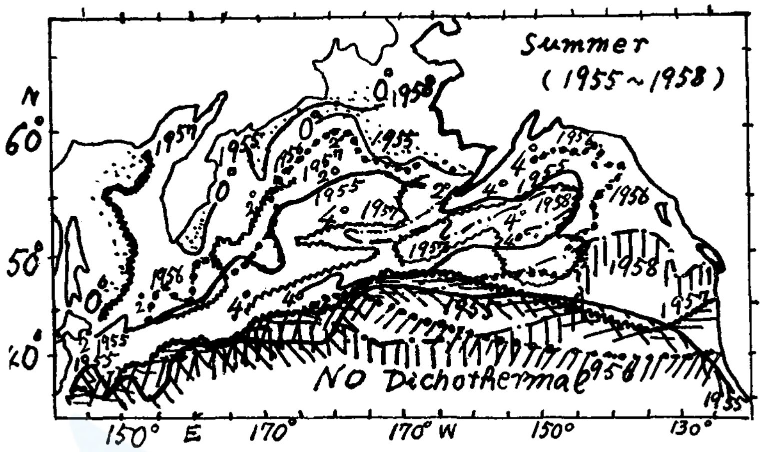

Fig. 4. Dichothermal topography (Summer, 1955~'58)

and again very scarce in the warmer (subtropical) water above 12–13°C.

Salmon wintering grounds are roughly specified by the dichothermal topography in the south of Aleutian and Kurile Chains.

Dichothermal structure in the western Subartic Waters is shallower and well developed in contrast to the eastern waters which is deeper and feeble. Those correspond to the densely concentrated salmons in the upper shallower layer in the western waters of Subarctic high sea compared to the deeply scattered fishes in the eastern waters.

The southern limit of distribution of dichothermal water and the northern limit of the intermediate (salinity minimum) water define the location of Polar Frontal Zone in which favourable fishing or whaling grounds are found in general.

3. *Surface salinity*

The distribution of salinity in each year from 1955 to 1958 are shown in Figs. 5, 6, 7, 8. Fig. 9 indicates the map of oceanic fronts based on the distribution of surface salinity during the summer season in the above years (1955–'58).

The whaling grounds seem to avoid the saline core lying at the Okhotsk Gyre, Bering Gyre and Alaskan Gyre (as well as Subtropical water) and to prefer the fringing zones around those cores of Gyres.

Salinity boundary looks to have more important meaning for the location of whaling grounds than water temperature, at least in the Subarctic waters does.

4. *Transparency of Sea Water or Clarity*

The distribution maps of transparency measured by Secchi's disk are shown in Figs. 10, 11, 12, 13 for each year during 1955–'58. Fig. 14 is the averaged distribution of transparency of them. The shaded turbid zones of less than 10 m. correspond to the several coastal watermasses and the Polar Frontal Watermass.

Eventually salmon stocks belong to each mother-river system and its associated coastal watermass. So, currents, eddies or gyres and the influenced extents of coastal waters in characteristic property (smell)

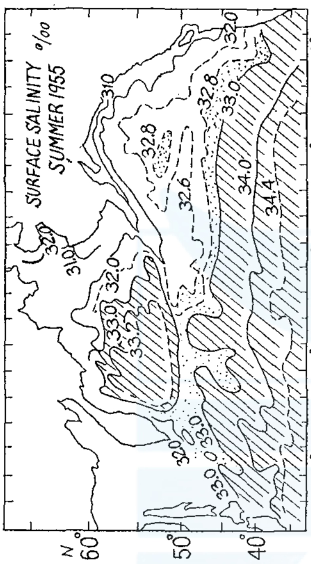

Fig. 5. Surface salinity in Summer of 1955.

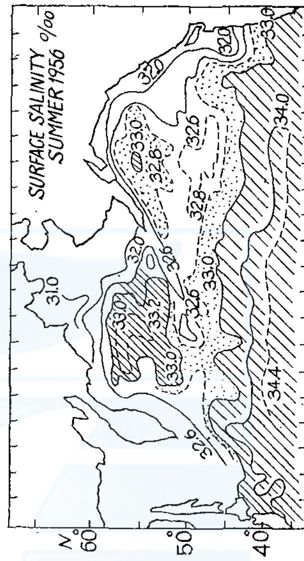

Fig. 6. Surface salinity in Summer of 1956.

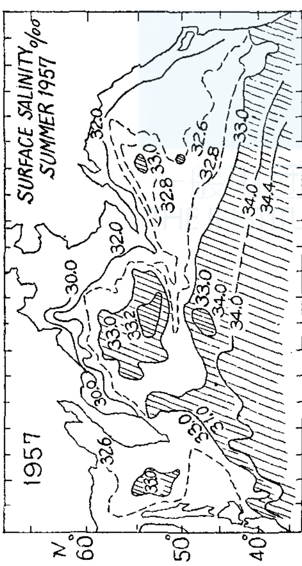

Fig. 7. Surface salinity in Summer of 1957.

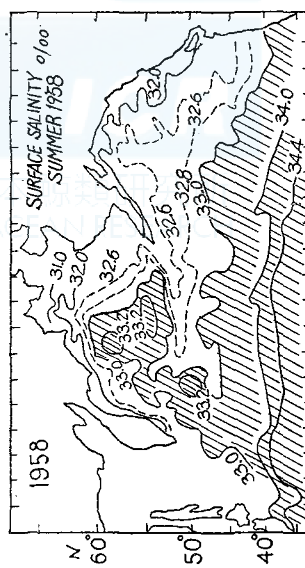

Fig. 8. Surface salinity in Summer of 1958.

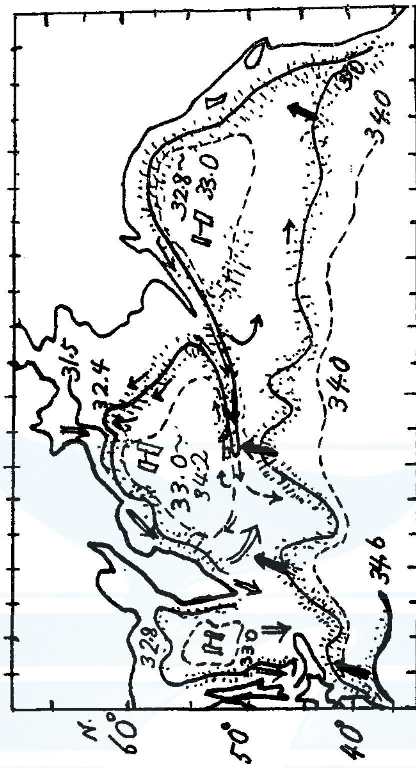

Fig. 9. Oceanic fronts of watrmasses based on surface salinity (‰), Summer (1955-'58).

Fig. 10. Transparency in Summer of 1955.

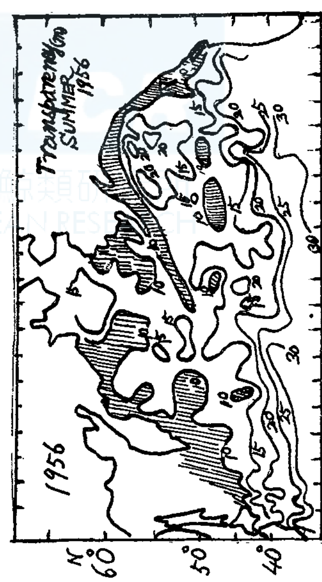

Fig. 11. Transparency in Summer of 1956.

correspond to the migratory routes, concentrated areas and segregated populations of salmons and whales. Turbidity is mainly composed of inorganic (mainly mud particles) and of organic (mainly planktonic origin) matters.

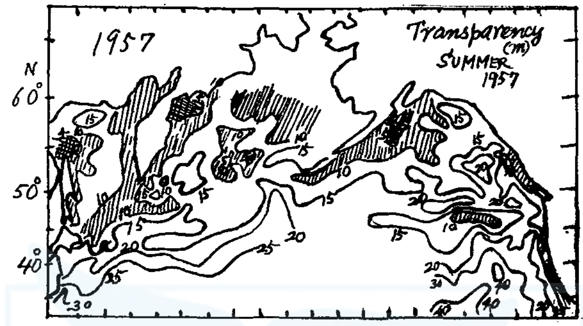

Fig. 12. Transparency in Summer of 1957.

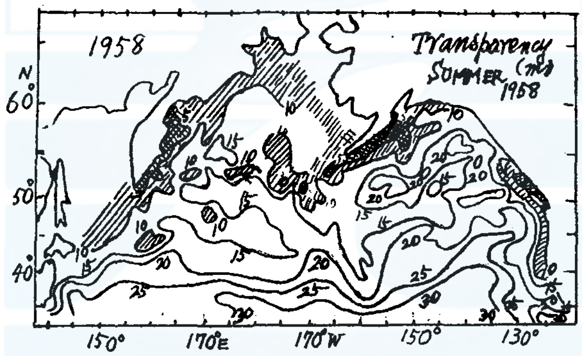

Fig. 13. Transparency in Summer of 1958.

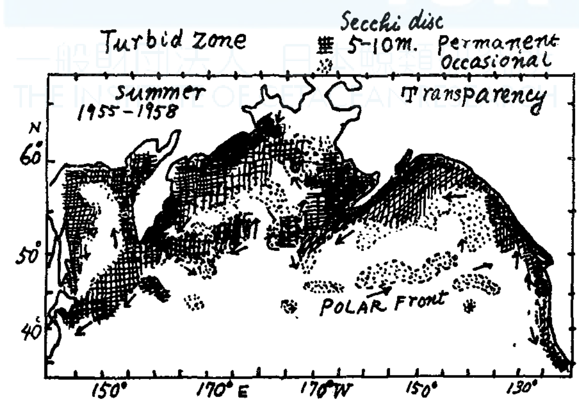

Fig. 14. Distr. of transparency in Summer of 1955～'58.

5. *Favourable whaling grounds at meridional sections*

Several meridional sections illustrate in Figs. 16–22 the oceanic frontal zone nearwhere the mode of whale catch (sperm whale and fin whal) are shown e. g. at the meridional sections across the Aleutian Ridge Fig. 15.

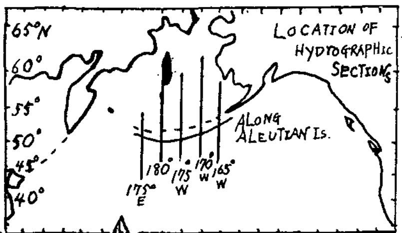

Fig. 15. Hydr. sections.

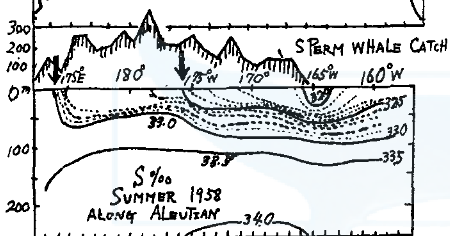

Fig. 16.

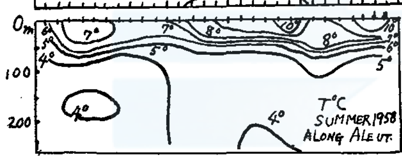

Fig. 17.

Temp. and saltinity sections along Aleutian Islands in contrast to the distr. of sperm whale catch.

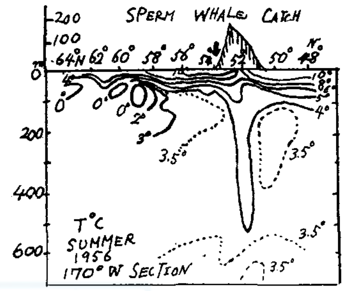

Fig. 19.

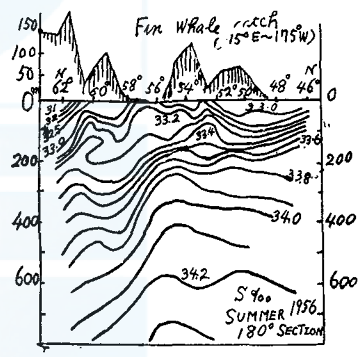

Fig. 20.

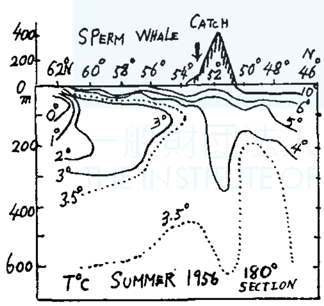

Fig. 18.

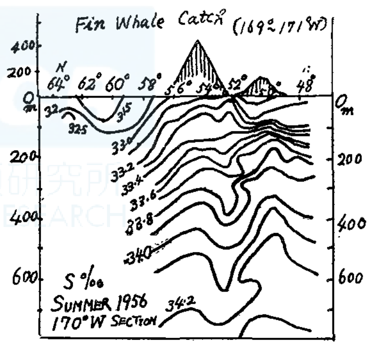

Fig. 21.

VERTICAL CIRCULATION AND WHALING GROUNDS

1. *Vertical mixing and convection in winter*

Table 1 suggests us the influencial depth of convectional mixing in the northern subarctic water from winter and spring to summer within the 200–300 m. depths from sea surface in winter almost completely and

TABLE 1 VALUES OF TEMPERATURE, SALINITY, σ_t, O_2, SATURATION DEGREE OF O_2 AND PHOSPHATE IN THE OKHOTSK SEA

ODOMARI*)								
1939, 2, March Winter 45°-41′ N 145°-10′ E			1939, 26, April Winter 46°-27′ N 144°-45′ E			1939, 13, May Winter-Spring 50°-47′ N 145°-09′E		
Depth m	Temp. °C	S ‰	Depth m	Temp. °C	S ‰	Depth m	Temp. °C	S ‰
0	−1.38	32.75	0	−1.19	32.25	0	−0.55	32.07
10	−1.49	32.77	10	−1.29	32.30	10	−1.31	32.39
25	−1.61	32.75	25	−1.33	32.30	25	−1.47	32.68
50	−1.54	32.75	50	−1.48	32.92	50	−1.45	33.04
100	−0.87	32.94	94	−1.59	33.01	100	−1.01	33.22
150	−0.25	33.10	143	−0.62	33.19	146	−1.03	33.24
200	0.43	33.28	196	0.71	—	195	−0.85	33.30
292	0.57	33.44	279	0.88	33.48	287	0.32	33.37
390	1.22	33.64	376	0.81	33.53	350	0.75	33.44

RYOFU-MARU*)						SOYO-MARU*)					
1942, 14, July Summer 50°-21′ N 148°-24′ E						1935, 21, Aug. Summer 40°-38′ N 146°-32′ E Bottom 3385 m					
Depth m	Temp. °C	S ‰	σ_t	O_2 cc	O_2 %	Depth m	Temp. °C	S ‰	O_2 cc	O_2 %	P mg/m³
0	8.44	32.18	25.02	8.01	119	0	12.80	32.45	6.55	106	25
10	7.68	32.16	25.10	8.53	124	10	12.67	32.45	6.68	108	50
25	1.32	32.38	25.92	9.49	119	25	4.56	32.83	8.45	115	35
50	−1.42	32.70	26.41	8.10	85	50	4.12	33.22	6.94	94	75
75	−1.54	32.83	26.42	7.92	93	100	1.41	33.22	6.94	88	90
100	−0.71	33.08	26.60	7.46	90	146	0.84	33.24	6.90	86	100
125	0.40	33.17	26.58	6.50	80	195	0.03	33.24	6.72	82	100
150	0.70	33.26	26.67	5.90	74	292	0.65	33.24	6.87	86	85
200	0.60	33.37	26.77	5.02	62	377	1.11	33.51	5.24	66	108
300	0.75	33.48	26.85	4.08	51	472	1.26	33.44	4.75	60	114
400	1.24	33.59	26.90	3.75	48	566	1.64	33.74	3.29	—	—
500	1.60	33.80	27.04	2.95	38	768	1.82	33.96	2.36	30	173
600	2.00	34.02	27.19	2.10	27	960	2.18	34.13	1.41	18	173
800	2.36	34.18	27.29	1.17	15	1440	2.22	34.43	1.38	18	150
1000	2.29	34.36	27.46	0.96	13	1929	2.01	34.54	1.48	19	156
1199	2.23	34.38	27.47	1.09	14	2893	1.88	34.54	2.04	26	160

*) Research vessel

gradually to the lower depths unto 500–600 m. incompletely with delayed phase lag in which saturation degree of dissolved oxygen is above 60% in the Okhotsk Sea. Contrary to the deep water below the 800 m. depth having 15–30%, the upper water of lower saline and richer oxygen is flowing out through the Middle Kurile Straits into the water of Pacific Ocean of different water type. Stronger convectional mixing continues in tne Okhotsk and Bering Seas to the end of May in the upper layer.

2. The schematic pattern of watermasses and currents in the meridional section are shown in Fig. 22.

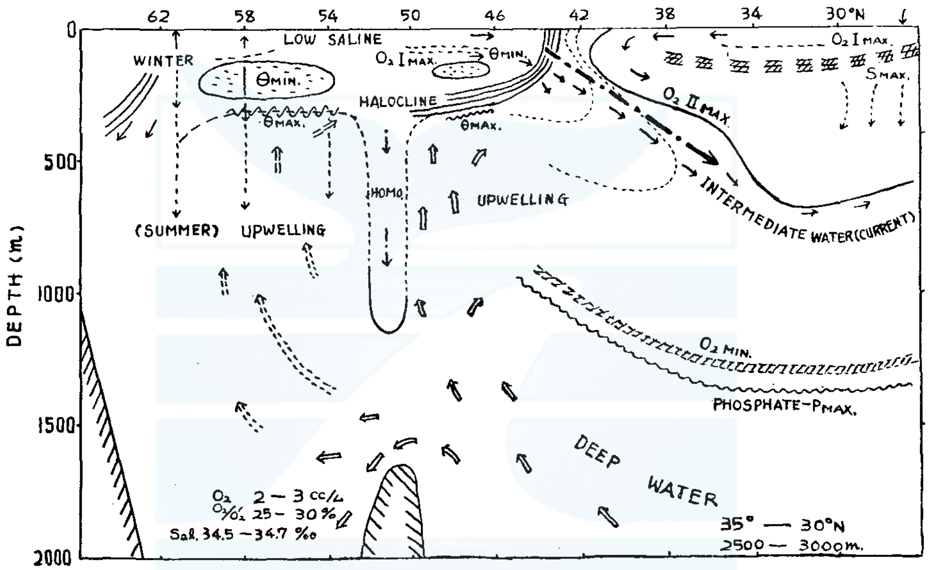

Fig. 22. Schematic circulation pattern in meridional section of North Pacific.

The inflow of Pacific Deep Water having salinity of 34.0–34.7‰ invades in the bottom layers of Bering Sea and Okhotsk Sea, overflowing the Aleutian and Kurile Ridges northwards which is basically different from the oceanographic structure in the North Atlantic Ocean.

3. In summer time the whaling grounds in the North Pacific Ocean cover the area of Subarctic Watermass lying in the zone of 48–64° N as their center.

The pattern of deep circulation in the North Pacific indicates also the general ascending current or upwelling in the higher latitudes. As favourable feeding grounds they depend on the higher productivity aroused by the general upwelling area which is similar to the Antarctic whaling grounds of fertilized waters by the prosperous upwelling process (Uda, 1961a). (Fig. 16–21)

4. We recognize the evidence of the Intermediate Current of Subarctic origin showing the second maximum of dissolved oxygen along the isopycnals of 26.20–26.80 and salinity minimum layer in the Polar Frontal Zone between the latitudes of 38 and 42° N.

WHALING GROUNDS IN RELATION TO HYROGRAPHY

The whaling grounds for each species in the Aleutian waters and Bering Sea north to 48° N during the years from 1955 to 1959 are shown in Figs. 23, 24, 25, 26, 27.

Fig. 23. Distribution of fin whale catch (1955–1959 accumulated).

1. We can not find fin whale grounds (Fig. 23) in the areas of the Bering Shelf Water of low salinity in the eastern part in the Bering Central Saline Water and also in the warm Alaskan Stream, probably due to the poor food-organisms.

Their grounds are located along the several oceanic fronts probably due to the plenty food-organisms concentrated by the vortical trains;

(α)....Anadir Front off the entrance of Anadir Bay,

(β)....Along the continental shelf edge particularly northwest to the southern tip of shelf edge north off Alaskan Peninsula,

(γ)....At the front of the warm South Aleutian Current and the cold Alaskan Gyre,

(δ)....Eddies east off Kamchatka Penninsula covering the water of Kamchatka—Komandorskii Islands—Attu Island.

As for example, sections at longitudes 180° and 170° W concerning water temperature and salinity indicate the relationship between the prosperous whaling grounds and the oceanic fronts, located between the cold, low saline and turbid water and the warm, saline and transparent water.

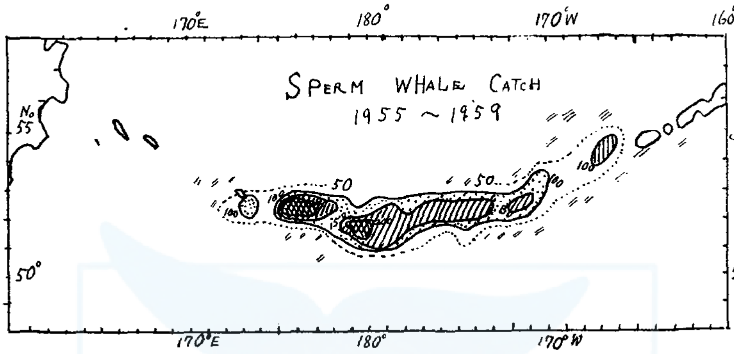

Fig. 24. Distribution of sperm whale catch (1955–1959 accumulated).

2. The sperm whaling grounds (Fig. 24) extend mostly around the Aleutian Islands, especially on the northern side where the upper and lower waters mixed well, almost showing homogeneous water temperature and salinity in the vertical and disappearance of dichothermal water, presumably due to the stronger turbulent mixing by tidal current and convectional mixing on the Aleutian Ridge and also suggesting the plenty food of squids around the Aleutian Islands Chain.

In the western part of the Subarctic Waters the dichothermal topography shows a shallower core depth of temperature minimum which may correspond the lower boundary surface of sperm whale migration.

3. The sei whale grounds during 1955–'59 (Fig. 25) developes mainly in the south of Aleutian Islands and concentrated to the top of the

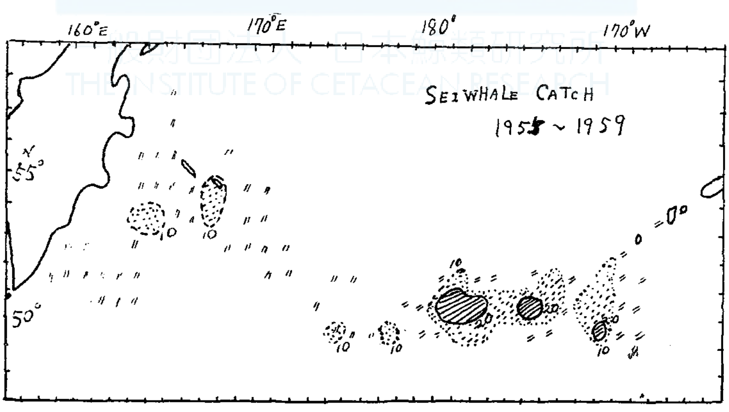

Fig. 25. Distribution of sei whale catch (1955–1959 accumulated).

South Aleutian Current in the south of Middle Aleutian (170° W–180°, 49°–52° N).

4. The humpback whale grounds during 1955–'59 (Fig. 26) also lie nearly along the south of Aleutian Chain.

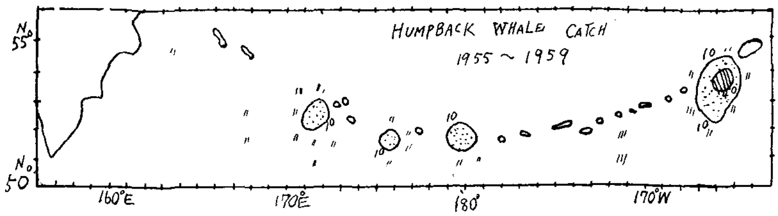

Fig. 26. Distributian of humpback whale catch (1955–1959 accumulated).

5. The blue whale grounds during 1955–'59 (Fig. 27) lie along the south of the Western Aleutian (165° W–180°).

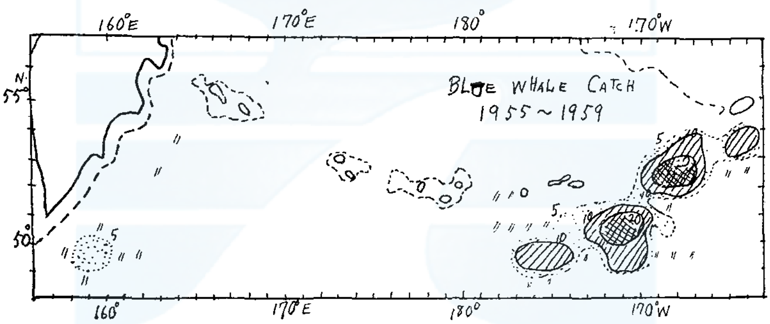

Fig. 27. Distribution of blue whale catch (1955–1959 accumulated).

CYCLIC CHANGE AND SEASONAL VARIATION

1. Seasonal or monthly variation of the distributed extents of water types or oceanographic elements (temperature, salinity etc.) shows rapid changing state of environmental conditions of salmon etc. from winter through spring to summer decade by decade, particularly in the Aleutian waters.

2. By his recent study (Uda, 1960, 1961b, 1962) (Fig. 2, 9) the author convinced that the pulsational cycle travels across the Pacific Ocean in the higher latitudes of prevalent westerlies flow west to east and come back from east to west in the lower latitudes of the prevalent Northeast Trade Wind (Rodewald 1959). The warm water intrusion in the western pacific occurs just concurrently with the cold water intrusion in the eastern pacific and vice versa (according to the past records of half a century).

3. The changing pattern of intruding shift from west to east appears to occur with the cycle of several years.

The superposed isolines of geostrophic flow in one map during 1955–'59 illustrates the above stated pattern of pulsation. Favourable catch year of salmon and whale corresponds to the warm intrusion in that area.

The head of warm water intrusion located in the waters, south of Hokkaido (in 1955), south of Kamchatka (in 1956), south of Aleutian Islands (in 1957) and off British Columbia—Northwest of U. S. A. (in 1958 and less in 1959) successively suggests us the migration pattern of pulsating Polar Front in easterly direction with the transpacific time interval of 3–4 years which is expected to reflect on the fisheries conditions of salmon, whale etc.

4. Temperature rise and fall in the ocean along Japan side occurs almost conversely to that along American side in the pacific during the fifty years 1910–'59. The intermediate pattern between those extrema on west and east coasts of pacific indicates the displacement of warmer or cooler waters in succession in the higher and middle latitudes and lower latitudes from east to west during the cycle years.

The anomaly chart of water temperature for each year during 1910–1941 and 1952–1959 indicates transpacific travelling pattern from west to east in the zone north to 30° N, on the contrary from east to west in tne zone of 30° N to 0° (equator) still in question though conceivably.

5. The core atomospheric pressure difference between the great high and low depressions in winter i. e. those between the Siberian High, the Aleutian Low and North Pacific High increased in the years from 1955 to 1959 in correspondence with the temperature rise in the east and temperature drop in the west during that period.

The increase of above pressure difference suggests us the accelerated geostrophic flow, and the intensified gyres with heat transport of warm watermass from west to east (refer to Fofonof, 1960–'61).

6. Cyclic change in the North Pacific Circulation composed of Subarctic (Cold Water) Circulation and Subtropical with Tropical Warm Water Circulation occurs with the period of 5–11 (in average 7–9) years.

7. Fluctuations of Kuroshio, California Current, North Equatorial Current and Peru Current (El Niño) might be correlated with the prediction indices from one to another.

REFERENCES

FLEMING, R. H. (1955): Review of the Oceanography of the Northern Pacific. pp. 1–43. Bull. No. 2. International North Pacific Fisheries Commission.

RODEWALD, M. (1959): Beiträge zur Klimaschwankung im Meere (11), Die Ostpazifische "Wärmewelle" von 1957/58, Deutsches Hydr. ZS. R. (5).

UDA, M. (1960): On the fluctuation and prediction of ocean temperature in the North Pacific. The Memoirs of the Kobe Marine Meteorological Observatory. Vol. 14. 1-16.

——— (1961a): Deep Circulation in the Antarctic Ocean. The Antarctic Record No. 11. pp. 831-835. Ministry of Education. Japan.

——— (1961b): Cyclical fluctuation of the pacific tuna fisheries in response to cold and warm water intrusions. M. S. distr. Pacific Tnna Biology Conference, Honolulu, Aug. 1961.

——— (1962): Oceanography of the Subarctic Pacific. Journal of the Fisheries Research Board of Canada (in press).

Fofonof, N. P. (1960, '61): Transport Computation for the North Pacific Ocean. 1955, '56, '57, '58, '59, '60. Fisheries Research Board of Canada. MS. Rept. Ser. (Oceanographic and Limnological). No. 77, 78, 79, 80, 85, 93.