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Pulsative Fluctuation of Oceanic Fronts in Association with the Tuna Fishing Grounds and Fisheries*

Michitaka UDA

Abstract

Firstly dense concentration of tuna (albacore-, yellowfin-. bluefin- and skipjack-) in the eddy systems along the oceanic frontal zones is noted. Long-term cyclic fluctuation of tuna fisheries is ascirbed to oceanic changes, particularly due to the meridional cold and warm water intrusions in response to the changing atmospheric circulation associated with the intensity and locality of the Siberian High, the Aleutian Low and the North Pacific High Depressions and the pressure gradients between them.

Further, the belts of favourable tropical tuna fishing grounds in the three great oceans are ultimately subject to the Equatorial Upwelling centered in the sea-regions of the Equatorial Countercurrent and the Equatorial Undercurrent.

In general, we recognize that tuna fisheries' rich years come in the warmer periods and poor years come in the cooler periods. The dominant year-classes of tuna reproduction appear in the warming phase, following the fertilization of seas due mainly to equatorward cold water intrusion from higher latitudes and stronger upwelling associated with the intensity of trade winds. The shallower topography of the subarctic Intermediate Water (salinity minimum) provides a good indicator of Equatorial Upwelling.

The decline of tuna catch due to overfishing and marine pollution in recent years is discussed.

In conclusion, the author proposes a reciprocal correlation of fisheries oceanographical conditions between the west and the east sides of the North Pacific and a pulsative propagation similar to the Planetary Wave along the Polar Frontal Zone in the Pacific.

1. Introduction

The explosive increase of human population in the world demands the comprehensive exploitation of marine food resources in the world's oceans including utilized and unutilized fish-stocks as well as an increased crop from marine culture. However, there exists a great flunctuation in some important fish populations due to the ever-changing natural environment (as a whole combined oceanic and climatic system), expanded fishing activities and recently increased marine pollution.

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Since 1952 Japanese fishermen have contributed greatly in exploiting new tuna fishing grounds in the world oceans, roughly from 50°N. to 50°S. centered in the tropical sea regions. Since 1960 tuna long-line fisheries have been declining (in terms of catch per unit fishing effort). Localization, reproduction and cyclic fluctuation of tuna fisheries are all related to oceanographic conditions which might be predicted through fisheries oceanographical surveys and forecasting systems.

The present paper is intended to contribute to understanding of the spatial and temporal variations of tuna abundance in relation to oceanic fronts, and other causes.

2. Localized Concentration of Tuna in the Eddies along Oceanic Fronts

The aggregation of tuna is to be found along oceanic fronts, localized in eddies, cool or warm, and in zones of upwelling. Variations in fish concentration and the location of tuna are associated with the growth, decay and change in position of the eddies, under the influence of the Polar Frontal Zones, the Subtropical Convergence and the Fronts near the Equator.

1) Localized concentration of albacore-tuna

i) Based upon fisheries oceanographic maps (5 days circular) published by the Tohoku Regional Fisheries Research Laboratory for a period of ten years (1951–'60) the maximum frequency of integrated catch was plotted against the warm ridge and cold trough of isotherms (Table 1). The longitudinal distribution of fishing locality shows albacore lying near the edge of the cold core axis, unlike skipjack which lie near the edge of the warm core axis, and bluefin-tuna, lying inside of the cooler coastal waters.

Table 1. Frequency of the localities of thermal ridge ($\theta_{max.}$) and thermal trough ($\theta_{min.}$) in the latitudes (35°–45°N.) during the years (1951–1960) in relation to the principal fishing localities of tuna.

Decade, Month, temp./Lg.		140°	141°	142°	143°	144°	145°	146°	147°	148°	149°	150°	151°	152°	153°	154°E
Early May	θ max.	1	3	0	1	1	0	1	0	–	–	–	–	–	–	–
	θ min.	1	1	1	0	0	0	0	1	–	–	–	–	–	–	–
Middle May	θ max.	0	9	3	1	0	2	1	1	1	0	–	–	–	–	–
	θ min.	5	3	0	2	4	2	1	2	0	1	–	–	–	–	–
Late May	θ max.	–	12	3	5	1	4	2	1	2	–	–	–	–	–	–
	θ min.	–	2	3	0	5	3	0	0	1	–	–	–	–	–	–
Early June	θ max.	–	13	13	6	4	6	1	1	2	–	–	–	–	–	–
	θ min.	–	5	6	5	2	0	1	1	4	–	–	–	–	–	–

Middle June	θ max.	–	23	19	6	2	2	1	2	3	3	–	–	–	–	–
	θ min.	–	9	5	2	3	3	3	3	1	6	–	–	–	–	–
Late June	θ max.	–	17	24	14	5	7	8	1	4	8	1	–	–	–	–
	θ min.	–	7	4	3	3	6	2	3	2	1	1	–	–	–	–
Early July	θ max.	–	11	22	18	4	3	4	6	3	8	4	2	0	4	0
	θ min.	–	8	9	7	1	0	8	1	1	1	1	0	1	1	2
Middle July	θ max.	–	2	19	26	32	10	8	12	8	11	3	4	–	–	–
	θ min.	–	10	20	3	4	8	6	5	9	0	4	1	–	–	–
Late July	θ max.	–	0	15	24	18	13	14	14	5	11	19	8	5	–	–
	θ min.	–	12	21	3	6	5	6	3	5	0	1	4	0	–	–
Early Aug.	θ max.	–	1	3	21	31	17	20	5	9	18	14	10	6	3	2
	θ min.	–	2	17	5	2	2	5	2	5	0	0	0	1	3	0
Middle Aug.	θ max.	–	3	8	13	33	12	12	8	11	12	8	2	4	6	3
	θ min.	–	5	10	0	0	2	2	1	5	0	2	0	0	0	1
From Early	θ max.	1	94	129	135	131	76	72	51	48	71	39	26	15	13	5
May to	θ min.	6	64	96	30	30	31	34	22	33	3	9	5	2	4	3
Middle Aug.	Integrated Bluefin	–	4	7	2	1	1	1	–	–	–	–	–	–	–	–
Mode (freq.)	Integrated Skipjack	–	2	4	4	3	4	3	6	3	3	2	1	–	–	–
	Integrated Albacore	–	–	3	1	–	2	1	3	–	2	3	–	–	–	–

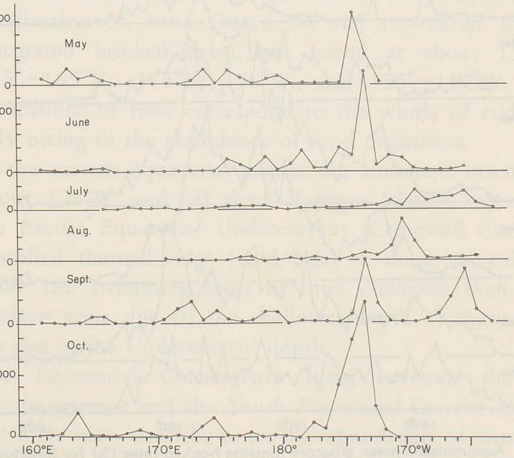

Fig. 1. Longitudinal distribution of longline albacore catch in the waters off Japan (35°-45°N), in 1938-1940.

ii) Exploratory albacore longline-fishing cruises were carried out in the fishing area covering 35°~45°N., 160°E.~160°W. from May to October during the years 1938–'40; favourable temperatures for albacore-tuna (15°~17°, 18°, 19°~21°C) were found. The longitudinal integrated albacore catch is shown in Fig. 1, indicating the peaks of catch at the longitudes of 161°~165°E., 171°~178°E., 173°W~176°W., and 171°~165°W.

iii) Based on the "Atlas of the Average Year's Fishing Conditions of the Tuna Longline Fisheries" (1958 edition, published by the Nankai Regional Fisheries Research Laboratory), the east-west distribution of integrated albacore hooked-rate and also the north-south distribution are shown in Fig. 2 and 3. Peaks at about 130°~140°E., 140°~150°E., 156°~164°E., and 170°E.~180° are indicated, suggesting a southerly shift of catch mode from 38°N. to 30°N. with the advance of months from October to March to the final southernmost east-west extension along the Subtropical Convergence.

Eddies along the meandering Kuroshio Front at the head of the cold water intrusion produce favourable albacore fishing areas. The vorticity of each eddy may determine the amount of tuna concentration.

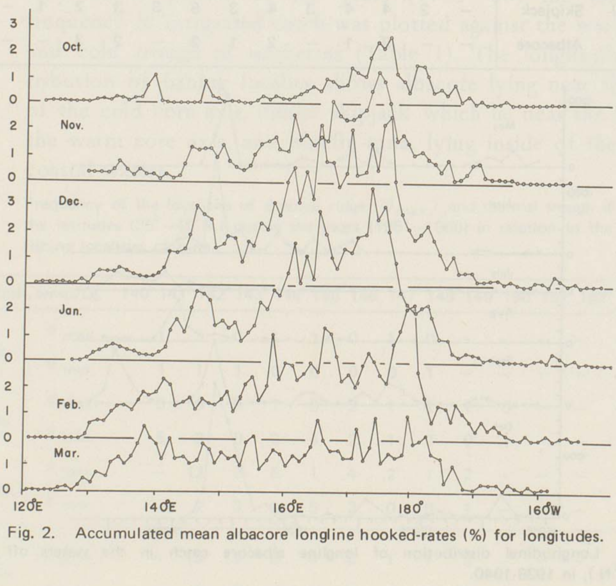

Fig. 2. Accumulated mean albacore longline hooked-rates (%) for longitudes.

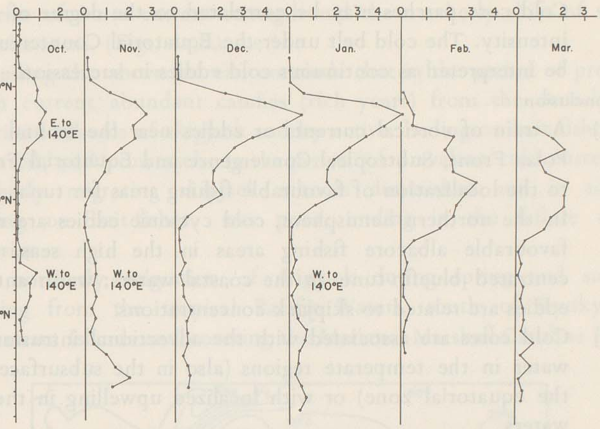

Fig. 3. Accumulated mean albacore longline hooked-rates (%) for each longitude.

iv) In the sea-region west to 140°E. the increased catch of albacore (integrated hooked-rate) between 30°N. and 20°N. suggests their migration along the Subtropical Convergence.

2) **Localized concentration of yellowfin-tuna**

i) The distribution of yellowfin-tuna in the explored fishing areas fished by commercial Japanese tuna boats shows a concentrated band along the Equatorial Countercurrent in the North Pacific. With this current zone several areas of remarkably concentrated localization of tuna (based on the contoured map for the integrated hooked rate), are found at about 135°~145°E., 155°~165°E., 175°E.~175°W., and 155°~157°W. These concentrations of tuna correspond to the whirls of eddies, conceivably owing to the abundance of food organisms.
In the eastern equatorial pacific the abundant catch areas lie at about 125°W. and off the Galapagos Islands, corresponding to the Pacific Equatorial Undercurrent (Cromwell Current) as the upwelled thermal ridge (cold belt) or dome of cold water has made the swimming layer of tuna shallower than that in the western zone due to the shallower depth of thermocline or to the rise in the Undercurrent depth.

ii) The Equatorial Convergence lying between the Equatorial Countercurrent and the South Equatorial Current at latitudes of 1°~3°N. may contribute to the abundance of tuna, partly by the concentration of food organisms and partly by constituting an environmental barrier to tuna.

Cold core patches may be correlated to the degree of upwelling intensity. The cold belt under the Equatorial Countercurrent can be interpreted as continuous cold eddies in succession.

3) Conclusion

i) A train of vortical currents or eddies near the frontal zone (i.e. Polar Front, Subtropical Convergence and Equatorial Front) lead to the localization of favourable fishing areas for tuna.
In the northern hemisphere, cold cyclonic eddies are related to favourable albacore fishing areas in the high seas, and concentrated bluefin-tune in the coastal waters; warm anticyclonic eddies are related to skipjack concentrations.

ii) Cold cores are associated with the advectional intrusion of cold water in the temperate regions (also in the subsurface layer of the equatorial zone) or with localized upwelling in the tropical waters.

iii) In conjunction with the seasonally changing pattern of oceanic eddies on the Kuroshio Front from May to June and those on the Oyashio Front from July to August, the localized concentration of quasi-stationary potential fisheries zones moves rapidly from one front to another and in the fall season it moves back southward again.

iv) Lastly, it is proposed that temporal changes in oceanographic and fisheries conditions are related to climatological changes and the relationships should be fully studied.

3. Cyclical Fluctuation of the Pacific Tuna Fisheries in Response to Cold and Warm Water Intrusions

In order to study the fluctuating tuna fisheries on both the west and east sides of the Pacific Ocean in relation to warm and cold water intrusions, catch statistics and fishery-biological surveys of tuna resources were taken and compared to the changing oceanic conditions of the Pacific Ocean.

1) The fluctuation of the Skipjack-tuna (*Katsuwonus pelamis*) fishery and its causes

In waters adjacent to Japan peak landings of skipjack occurred in the following years: 1912–'15, 1917–'20, 1927, 1933–'34, 1936–'38, 1942, 1956–'58. The years of 1944–'50, representing continued poor catches of skipjack, correspond to the prevalent cold current which adversely affected the fishery by the reduced feeding on live-bait and the delay of the main fishing period by about two months compared to the normal year before World War II.

Since the year 1956 conditions have improved remarkably, following the rise of warm current strength and the northerly shift of sardine fisheries areas. (Figs. 4a,b,c,d,e.)

Compiling the above we can conclude that in the period of prevalent warm current abundant catches (rich years) from the densely concentrated schools of skipjack and by active feeding on bait-fishes have occurred, and conversely in the period of prevalent cold current the northerly migrating skipjack schools diminished and in addition feeding on bait-fishes was poor, ending in the failure of the fisheries.

The northerly migration of skipjack during spring and summer, starting from the tropical Pacific Waters, south of Ryukyu and Ogasawara Islands and covering the Mariana, Marshall-Caroline Islands,

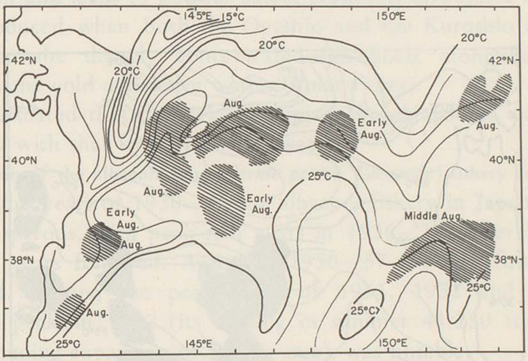

Fig. 4a. Surface water temperature on the skipjack fishing ground in August, 1955, the year of most northerly warming.

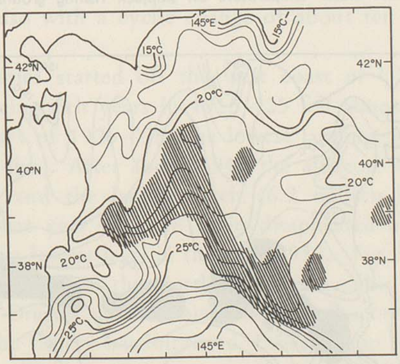

Fig. 4b. Surface water temperature on the skipjack fishing ground in August, 1956.

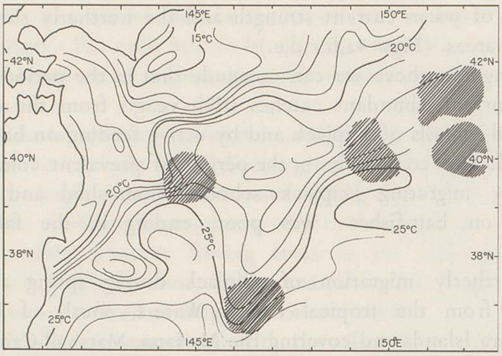

Fig. 4c. Surface water temperature on the skipjack fishing ground in August, 1957.

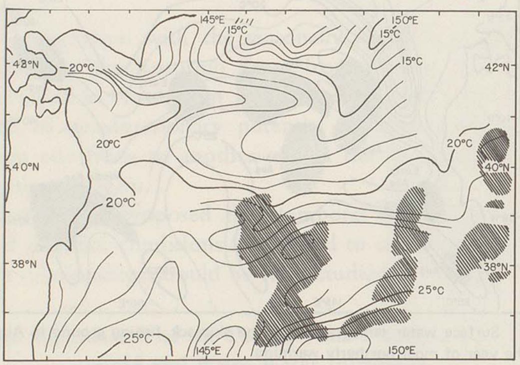

Fig. 4d. Surface water temperature on skipjack fishing ground in August, 1958.

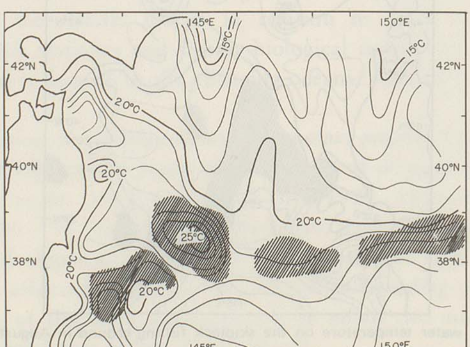

Fig. 4e. Surface water temperature on the skipjack fishing ground in August, 1959.

Phillipine Islands, Celebes and Formosa etc., follows two main routes: one along the Taiwan-Ryukyu-Kyushu-Shikoku Island, and another along the Mariana-Bonin Ridge-Idu Islands, and then a joint route into the North-eastern Sea of Japan.

It was postulated that the recruitment of skipjack is favoured by the enriched zones associated with the Equatorial Countercurrent and near the Equator. Starting from those tropical waters skipjack population (composed mainly of medium-sized fish) enter Japanese waters. When the warm Kuroshio water spreads over a broader northern area, more skipjack become available to the Japanese fishery.

Conversely, a stronger Oyashio cold current hinders the skipjack migration and leads to a lower catch. However, favourable catches are also produced when both the Oyashio and the Kuroshio are strong, owing to the densely concentrated fish-shoals along the boundary between the cold and warm waters (Polar Front).

It is postulated that the yield of skipjack from Japanese waters varies inversely with that from American waters.

2) **Fluctuation of the albacore-tuna (*Germo germo, Lacepede*) fishery and its causes**

During the years of 1930–'40 the albacore fishery in Japanese waters was prosperous, with peak rich years in 1936–'38. After World War II poor years followed. Again, in 1950–'57 the rich fishing period returned. Among the peak years of 1951, 1952 and 1957, the greatest peak in 1952 (its landing in summer 41,250 tons, with a corresponding expansion of fishing area), was notable.

The fluctuation of the albacore fishery (or the periods of rich and poor years) occurred somewhat earlier than that of the skipjack fishery, and also with a cyclic change of about ten to twenty years interval.

Albacore fisheries started off the west coast of USA in 1910 and after experiencing rich years in 1915–'25 fell almost into extinction during the years of 1926–'38 (the lowest landing, in the year 1933, was only 500 lbs.). After about 1941 the albacore fishery entered a richer period, and the largest catch (6.2 million lbs.) occurred in 1950. After that year albacore again disappeared and the declining yield reached its lowest level in the year 1953. (Fig. 5).

However, since 1956 in the Northwestern sea-region of the USA off the States of Oregon and Washington, the albacore have tended to increase and the fishery has improved. Especially in the years of 1958 and 1959 big albacore catches occurred corresponding to the northward shift of their fishing localities at the time of a warm water intrusion.

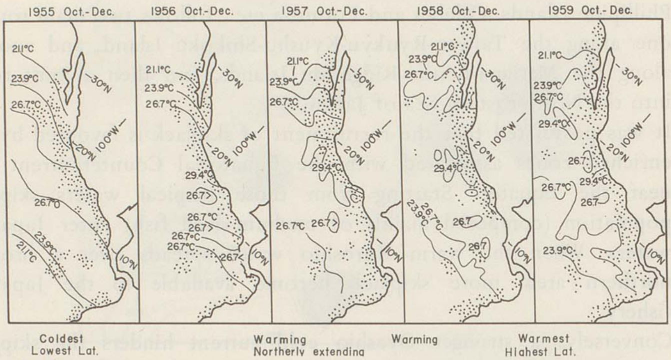

Fig. 5. Surface temperatures on yellowfin and skipjack tuna fishing grounds in Central American Waters (BLACKBURN, 1960).

It is postulated that the variations of albacore catch in Japanese waters and that in the Eastern Pacific waters occur in a reciprocal manner, as was found to be the case for skipjack. It is further postulated that the temperature in the eastern and western Pacific vary in a reciprocal manner, with pulsations travelling from west to east in the zone of prevailing westerlies, returning in the tropical lower latitudes dominated by the easterly trades.

Intrusions of cold and warm waters along the continents may be related to fluctuations in atmospheric pressure-systems. During 1955–'59, an increase of pressure difference or pressure gradient between the Aleutian Low, Siberian High and the North Pacific High corresponded to a period of cooler temperatures in the western Pacific and warmer in the eastern Pacific.

Geographical variations in the location of the North Pacific High in winter and spring also affect the water temperature through wind-systems. Movement of the North Pacific High to the northwest results in warm intrusion in the western Pacific and good albacore catches, the inverse of the eastern Pacific. Movement of the North Pacific High to the southeast corresponds to cool water intrusion in the west with poor catches of albacore, reciprocal to the warm water intrusion in the east with good catches.

3) **The fluctuation of the bluefin-tuna (*Thunnus orientalis*) fishery and its causes**

Bluefin-tuna migrate northward from winter to summer along both the east and west coasts of Japan, and from the fall season to winter southward near the edge of cooler coastal water (temperature 18°-21°C) or concentrated into eddies corresponding to upwelling, forming localities favourable for fishing by means of purse-seine, trolling, longline, harpooning and set-net.

Inspecting old historical records of bluefin-tuna fisheries in Japan, we find the big catches in about 1891 and 1939-'40 (rich period in 1930-'40). During the period 1941-'48 bluefin-tuna almost disappeared from Japanese waters. Since the year 1950 young tuna have again appeared in the waters adjacent to Japan. The yield of the tuna fishery has improved year by year with an increase of average body weight and age group. Tuna catches off northern Japan (e.g. Aomori Prefecture) show peaks in the year of 1902-'19, 1930-'40, and 1952-'57 with an interval of about 20-30 years.

The bluefin-tuna along the coasts on the central Japan Sea side, e.g. Noto Peninsula, were poor in 1921-'26 (cooler period), rich in 1928–'38 (warmer period), poor in 1944-'53 (cooler period), and comparatively rich in 1954-'60 (warmer period). Notable rich catches of bluefin-tuna and sardine were taken during the period 1933-'40 from Kyushu to Saghalin along the Japan Sea coast and from Taiwan to Kurile along the Pacific coast.

However, both declined abruptly from the year 1941 (with the cold water intrusion); again since about 1950 small-sized (young) bluefin-tuna have been appearing year by year. The catch has since increased year by year with an increase of body size and the expansion of the migrating area to the north. The average body weight was 37.3 kg. in 1950 and 114-150 kg. (large-sized tuna) in 1956, with favourable catches off Aomori, Iwate and Miyagi Prefectures in summer and fall in that year.

Thus, bluefin catches off the coasts of Japan have also shown periodic fluctuations, with a decline in catch associated with the period of cold water intrusion, and an increase in catch with periods of warming. These fluctuations may be attributed to the dominant brood strength during the period of rising temperatures. When cool waters intrude southward into the spawning grounds, one or two year-classes are seriously affected. However, these cooler waters are relatively rich in nutrients, and with the trend reversed to warming, succeeding year-classes find plentiful food and favourable thermal conditions for reproduction and growth and also for their northward migration into Japanese waters.

In this way, we have a cyclical situation: a reduction of year-class strength and the decline of the fishery during a cool period in surface waters, is followed by an increase of brood strength during the subsequent period of warming and a more ecologically favourable situation resulting from the enrichment of surface water during the cool period.

Hence during the period of cold water intrusion (1941-'45), low survival and poor recruitment led to subsequently long-continued poor years, and the resulting increase in fertility in the southern subtropical waters in the period 1945-'49 could have affected the potential productivity of tuna resources. From 1949 the rising water temperature might have produced a triggering action in the sea-region in which abundant small tunny of 0-age group appeared. Following that year the bluefin-tuna fishery continued to thrive for nearly ten years. It is almost certain that the appearance of the old population of largest tuna alone unaccompanied by young tuna is the sign of the end of its prosperity (as seen in 1939-'41 and 1957-'58).

The years in which the meandering of the Kuroshio (1935-'45) followed the warmer period continued to the cooler period in 1941-'48 (declining Kuroshio). Since 1949-'50 the Kuroshio has been recovering its strength (i.e. warmness). But again in 1955-'56 slight and in 1959-'61 a marked meandering pattern of the Kuroshio recurred, with a corresponding recent decline of the bluefin catch (since 1959).

4) Conclusion

The condition of skipjack-, albacore-, yellowfin-, and bluefin-tuna fisheries show common characteristic features in relation to environmental conditions, especially to the fluctuation of warm water and cold water intrusions. The warmer period favours the migration, population size, and catch of tuna.

However, the cooler period premises a succeeding rise in reproduction potential or recruitment of the tuna population within a number of years. The cyclic fluctuation of tuna fisheries occurs in this way and could be predicted by combined oceanographic, climatological, and fishery-biological research.

4. Cyclic Changes in the Pacific Circulation and Fisheries Production with Relation to Atmospheric Changes

The cyclic changes of the Kuroshio Current, with upwelling of anomalous cold water-masses, and of the Oyashio Current, with changes in the Oyashio Undercurrent Extension carrying lower saline Subarctic Intermediate Water southward, are reflected by fisheries in the North Pacific. The importance of drift-migration in assessing the population size of commercial fishes must be stressed. A kinematical theory of fish-migration linked to the cyclic changes of fish-stocks in accordance with pulsating oceanic climate is proposed for each migration route of fishes (skipjack-, albacore- and bluefin-tunas, saury, mackerel, yellowtail, common squid) characterized by a closed circuit of the specified oceanographic regime. The migration most probably obeys the cold and warm circulation gyrals. The effect of changing monsoons on the reversal of fish-migration in response to the rise and fall of water temperature is marked in the seas adjacent to the Asiatic continent.

The cyclic changes of atmospheric depressions (the Siberian High, Aleutian Low, Pacific Highs and Equatorial Low), typhoon paths, air transports and resulting oceanic changes, and coastal discharge due to precipitation seem to affect reproduction potential and abundance of fishes.

Particularly, emphasis is placed on the effect of "Equatorial Upwelling" of Subpolar Intermediate Water as well as of its coastal upwelling, cold water intrusion toward the equator and warm water intrusion toward the pole, on the reproduction potential of fishes. The changes affected by the severe winter monsoon in 1963 (and also 1964) with the shift of the Kuroshio Stream axis southward and reduction of the volume transport of the Tsushima Warm Current to half of its normal amount caused mass mortality of fishes in the winter of 1963, and fertilization of tropical and subtroical lower latitude waters by the cold water intrusion resulted in the increase of reproduction potential and population size of jack-mackerel, pacific mackerel, yellowfin-, bluefin- and skipjack-tunas.

The strong northward intrusion of the New Guinea Current, similar to the Somali Current in the Indian Ocean and Guiana Current in the Atlantic Ocean, becomes marked in summer as the extension of the South Equatorial Current or northerly transgression of the South Pacific Central Water corresponding to the intensified air transport across the equator from the south in the northern summer, and is noted for the prediction of fluctuation of tuna fisheries. Assuming actual circulation $v = v_g + v_w$, where v_g denotes geostrophic flow and v_w wind-current, respectively, we can obtain v_w from the pressure-field (direction of current along isobar and current-speed proportional to pressure gradient) and its transport.

The stronger winter monsoon in the northwestern Pacific causes cold water intrusion toward the equator from higher to lower latitudes. Conversely, the summer monsoon and northward movement of a typhoon causes warm water intrusion additional to the northward Kuroshio intrusion due to its anomalous meandering. In contrast to the pressure-system, wind-system and current-system in 1955 (summer and winter) and those in 1958, the oceanographic conditions (thermal conditions) showed extreme change on the western (Japanese) side and on the eastern (American) side from the warm to cold extremum and vice versa.

Most frequently there exist two gyrals in the Central Pacific of mid-latitudes, termed by SVERDRUP (1947) the western and eastern

North Pacific Gyrals. Nearly on the boundary of these two gyrals we can remark a SE-SSE-ward cold subarctic stream (named as the East Kamchatka Current Extension) between 160°E. and 180° (date-line) in latitudes of 50°-30°N. as a fertile water area. It is more obvious at the depths of 100-300 m. in the subsurface layer along the Emperor Sea Mountain, or Mid-Pacific Ridge, forming favourable fishing grounds for salmon, saury and tuna (also whales) from north to south (UDA, 1971).

The basic patterns of annual circulation and thermal structure are almost laid down in winter by the basic pattern of pressure-systems in that year, particularly by the pressure gradients among the Siberian High, Aleutian Low, and North Pacific High depressions. The difference between those core-pressures is almost proportional to transports and correlated to the intensity of intrusions, based on the maps computed by FOFONOFF (1961, 1963) in the period 1950-'60. The pressure-difference between the Equatorial Trough and the North Pacific High (an indicator of the Northeast Trade Wind) is important to the meandering Kuroshio Current as well as the occurrence of *El Niño* corresponding to the weakening of Trades.

The pressure difference between the Aleutian Low and the North Pacific High might be correlated to the warm water intrusion from fall to spring along the west-offing of the Northwest American Continent and consequently to the prevalence of the Alaskan Stream in spring and summer.

Divergence and convergence of currents arising from the change of wind-circulation influence the development of eddies, stable and persistent for orographic conditions, and ultimately fertilization of fishing areas and concentration of fishes.

5. Upwelling of the Subpolar Intermediate Waters in Tropical Oceans, in Relation to the Highly Productive Zones Including Tuna Fishing Grounds

In the Equatorial Pacific Ocean, the areas of higher productivity and the most favourable tuna fishing grounds (mainly yellowfin-tuna) are mainly located in the vicinity of the upwelling areas of the Subarctic Intermediate Water from the north. The shallowest zone of salinity-minimum in the Subarctic Intermediate Water, reaching 100-200 m. depths beneath the North Equatorial Countercurrent, corresponds to the most favourable yellowfin-tuna areas. (Fig. 6).

As one of the results of the participation of Japan in IIOE (1960-'64), throughout the whole of the surveys, including the presurvey of 1960, we found a remarkable zone of discontinuity (frontal zone) at the meridional hydrographic sections near the latitudes around 15°S. in the Eastern Indian Ocean and a conspicuous upwelling area of cold, fertile water located at the south-offing of the Sunda Islands, indicating the influence of Subantarctic Intermediate Water and the Antarctic Bottom Water upon the upper tropical waters. (Figs. 7 and 8).

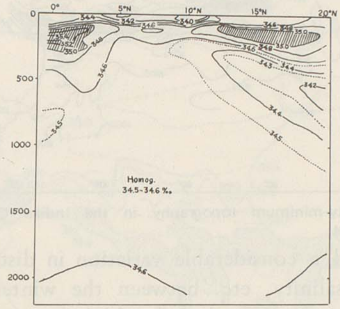

Fig. 6. Salinity section along 135°E., Nov. 1958, "UMITAKA MARU", in the Pacific Ocean.

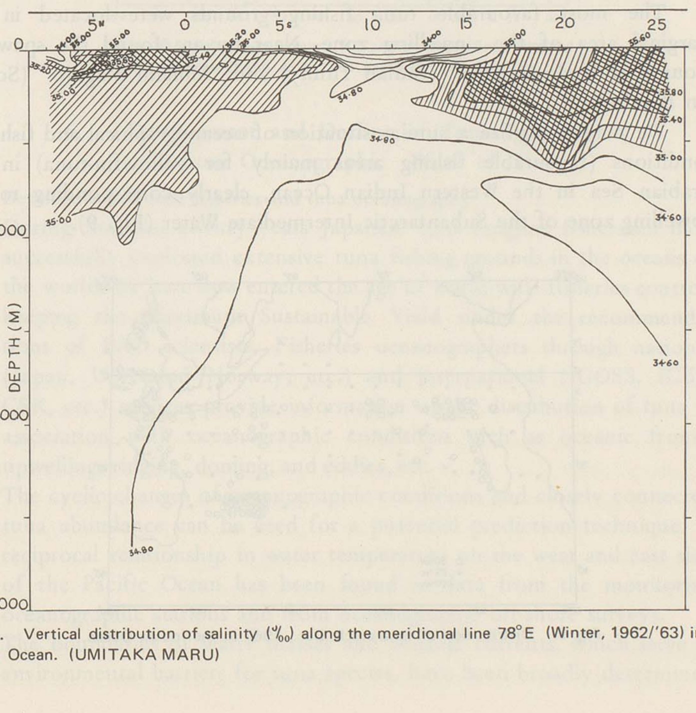

Fig. 7. Vertical distribution of salinity (‰) along the meridional line 78°E (Winter, 1962/'63) in the Indian Ocean. (UMITAKA MARU)

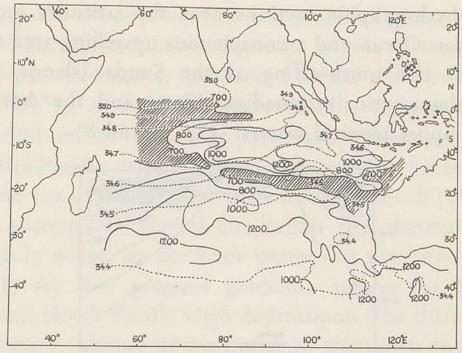

Fig. 8. Salinity-minimum topography in the Indian Ocean. North Winter, 1960-'64.

We have noticed a considerable variation in distribution patterns of water temperature, salinity, etc. between the winters in 1962-'63 and 1963-'64, showing the northward shift of whole current-systems and the above-mentioned upwelling area of cold water in response to a great change in meteorological conditions.

The most favourable tuna fishing grounds were located in the marginal area of the upwelling zone. Near by are found the spawning grounds of "Indo-Maguro" (Indian Tunny) and "Minami Maguro" (Southern Bluefin).

We may recognize a similar situation of oceanographical and fisheries conditions (favourable fishing areas mainly for yellowfin-tuna) in the Arabian Sea in the Western Indian Ocean, clearly corresponding to the upwelling zone of the Subantarctic Intermediate Water (Fig. 9).

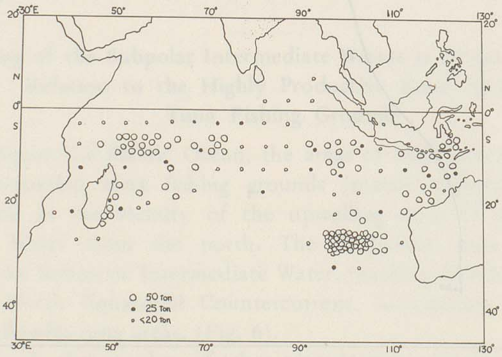

Fig. 9. Distribution of tuna catch, Dec., 1963 in the Indian Ocean.

In the Equatorial Atlantic Ocean we can observe a similar situation, with the most favourable tuna fishing (longline) areas located in the upwelling zone of the Subantarctic Intermediate Water (corresponding to shallower salinity-minimum topography and a zone rich in nutrient salts). (Fig. 10).

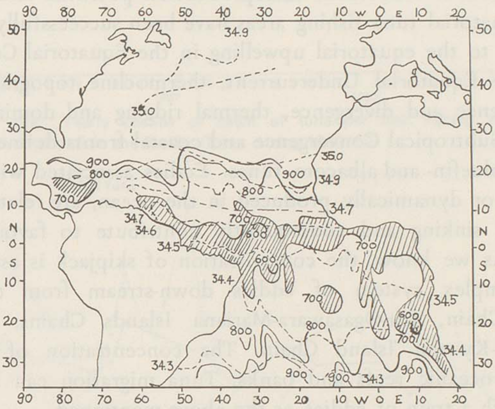

Fig. 10. Salinity-minimum (%) and its depth (m.) adapted from Atlantic Ocean Atlas (F.C. FUGLISTER, 1960).

6. Development and Decline of Tuna Fisheries from Oceanographic Point of View

1) Development of tuna fisheries and tuna oceanography

During the past twenty years Japanese tuna longline fishermen have successfully exploited extensive tuna fishing grounds in the oceans of the world. We have now entered the age of world-wide fisheries control, keeping the Maximum Sustainable Yield under the recommendations of FAO scientists. Fisheries oceanographers through national (Japan, USA and Norway, etc.) and international (IGOSS, ICES, CSK, etc.) services provide information of the distribution of tuna in association with oceanographic conditions such as oceanic fronts, upwelling, ridging, doming, and eddies, etc.

The cyclic changes of oceanographic conditions and closely connected tuna abundance can be used for a potential prediction technique. A reciprocal relationship in water temperature on the west and east side of the Pacific Ocean has been found in data from the monitoring oceanographic stations and from oceanographic off-shore surveys.

The boundaries of water masses and oceanic currents, which serve as environmental barriers for tuna species, have been broadly determined in the world oceans. Localization of tuna is also associated with some surface indicators of oceanic fronts, such as current-rips, slicks, discolored bands, drift-woods, algae or flotsam, flocks of sea-birds, companies of whales or sharks, foam-lines, etc. The change in oceanographic structure has a bearing on the migration of tuna and fluctuation of fish-stocks or reproduction potential and recruitment. The equatorial tuna fishing areas have been succeessfully delimited in relation to the equatorial upwelling in the Equatorial Countercurrent and the Equatorial Undercurrent, thermocline topography, lines of convergence and divergence, thermal ridging and doming. The Polar Front, Subtropical Convergence and coastal fronts define the distribution of bluefin- and albacore- tunas. Eddies associated with ridges and islands, or dynamically produced in the ocean, are related to upwelling and sinking and consequently contribute to favourable fishing areas. As we know, the concentration of skipjack is associated with the complex system of eddies down-stream from the Hawaiian Islands-Chain, Izu-Ogasawara-Mariana Islands Chains, and Taiwan-Ryukyu-Kyushu Island Chain. The concentration of tuna occurs around oceanic reefs and banks. Tuna migration can be associated with such a train of eddies as the above-mentioned.

In the years of anomalous meandering of the Kuroshio, tuna aggregate around upwelled cold waters and migrate further north than normal along the meandering stream. In *El Niño* years, tropical tuna are much were scattered than in normal years, and also may occur in abundance further to the south than normal.

2) **Declining Trend of Tuna Hooked-Rate in Recent Years**

NAKAGOME (1960, '62, '63) studied the hooked-rate (catch/100 hooks) of tuna-longline fishing in the world oceans and found a general trend of decline in recent years.

The present author has also investigated the tuna catch per boat per day in the Pacific, Indian and Atlantic Oceans throughout the years of 1960, 1961, 1962, based on materials from the wireless telegraphic communication of the fishing boats belonging to the Prefectures of Shizuoka, Mie and Kochi which were provided by the courtesy of Mr. Sueyoshi RACHI, former chief fishing conductor of the Seisho Maru II, and on the materials from the ten days rapid communication fishing charts distributed by the Fishery Oceanographic Research Laboratory of Tokai University; a similar conclusion was reached, of a marked general trend of decline of catch in a logarithmic way:

$y = a\, e^{-kt}$, as shown in Figs. 11a and 11b.

Average catch of tuna per day per boat = (hooked rate × hooks × frequency of operation)/day, shows a successive decay from an initial

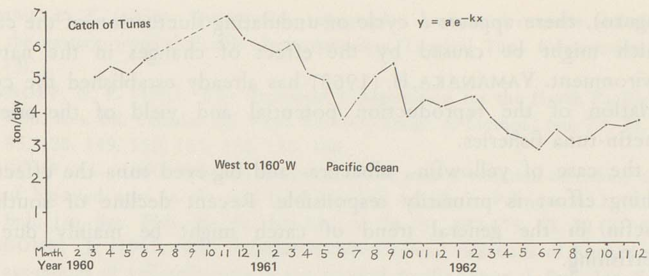

Fig. 11a. Yearly decline of catch of tuna per unit fishing effort (tons/day/boat) in the Pacific Ocean during 1960-'62.

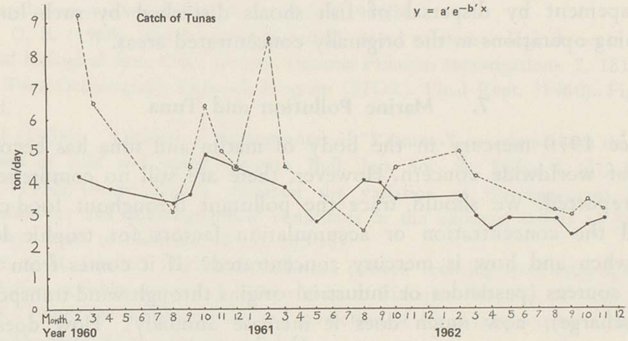

Fig. 11b. Yearly decline of the catch of tuna per unit fishing effort (tons/day/boat) in the Indian Ocean during 1960-'62.

upper level starting in 1960, through the levels of about 4 tons and 3 tons (medium level), falling off to a lower level of the order of nearly 2 tons in 1962 and threatening to deteriorate below the economically balanced level.

The rate of decay in the above corresponds to a factor of more than 20%. Meanwhile, the number of tuna fishing boats has shown an increase of about 20% and considering the size increase of the fishing boats and growing fishing capacity by technological improvement, it has resulted in the increase of fishing effort at a rate of well over 20% annually.

Therefore, the decline described above might be attributed mainly to overfishing and can hardly be accounted for by the changing natural environment.

In the case of bluefin-tuna, however, including Australian Southern Bluefin Tuna (Minami Maguro) and Indian Ocean Bluefin Tuna (Indo

Maguro), there appears a cycle or undulating fluctuation of the catch which might be caused by the effect of changes in the natural environment. YAMANAKA, H. (1965) has already established the cycle variation of the reproduction potential and yield of the oriental bluefin-tuna fisheries.

In the case of yellowfin-, albacore- and big-eyed tuna the effect of fishing effort is primarily responsible. Recent decline of southern bluefin in the general trend of catch might be mainly due to overfishing.

The decline of catch remarkable everywhere just often exploitation of virgin fishing grounds has begun might be partly due to the effect of escapement by dispersal of fish shoals disturbed by such longline fishing operations in the originally concentrated areas.

7. Marine Pollution and Tuna

Since 1970 mercury in the body of marlin and tuna has become a subject of worldwide concern. However, there are still no comprehensive studies reported. We should trace the pollutant throughout food-chains and find the concentration or accumulation factors for trophic levels. Where, when and how is mercury concentrated? If it comes from some artificial sources (pesticides or industrial origins through wind-transport or river discharge), how much does it increase annually? How does the sea-dumping of industrial wastes in general (including oil, heavy metals, PCB, DDT, sludges, sewage, and radioactive wastes) affect the population of tuna (eggs, larvae, juveniles, young and adults for spawning) and their food organisms in quantity and quality?

At least oil pollution, increasingly covering whole seas and oceans year by year, may seriously affect tuna abundance (by damage to eggs and larvae) and quality (oil smell and flesh contamination by dangerous carginogenic aromatic substances) in the future, to the extent that we fail to prevent it.

Aknowledgement

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マグロの漁場と漁業に関連する海洋前線の脈動的変動

宇田道隆

要　約

1952年以来日本のマグロ漁場は全世界の海洋に向い拡大されたのが、1960年ごろから単位努力当り生産が低下し出した。筆者は既往の漁海況資料をもとに研究し、海洋前線に沿う渦流列のマグロの局地的集群をビンナガマグロ、キハダマグロ、クロマグロ、カツオについて示し、次にマグロ漁況の長年周期的変動が海況の変動、特に暖流寒流とその南北貫入の強度に応じて現れること、それが大気大環流の高低気圧（北太平洋高気圧、シベリア高気圧、アリューシャン大低気圧の位置と強度）および気圧傾度に対応していることを示した。

熱帯海洋の赤道反流域、赤道潜流域を中心とする三大洋でのマグロ好漁場帯は、亜寒帯中層水の赤道湧昇によることも実証した。さらに最後に近年日本マグロ漁業の生産減衰について考察し、あわせてマグロ漁業をおびやかしつつある海洋汚染について考察の結果をのべた。すなわち、海況の変動に応じて長年の変化はあるが、日本近海暖流優勢（高水温）期に好漁、低温期に不漁、冷水南方貫入による肥沃化後、暖化の起ると共に卓越年級の発生、再生産増をみる機構についてのべると共に、乱獲と海洋汚染による不漁化と共に再生産の質的被害（目に見えない）の大きく現われることをのべた。海況、漁況の北太平洋東西逆相関の事実を示し、これがどのようにして起るかを気象と海流変動の北太平洋で西から東に向って極前線上にプラネタリ波的の波状の脈動となって現れることを過去の資料によって明かにした。(1952－'65年の資料を中心とした。)