RELATION BETWEEN THE DISTRIBUTION OF TUNAS AND WATER TYPES OF THE NORTH AND SOUTH PACIFIC OCEAN*

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Introduction

Distribution of tunas was studied by NAKAMURA, YAMANAKA (1959) in relate to the current system, and then to the water mass by the authors. For these studies, the oceanographic data were grouped into winter and summer seasons because of the scarcity of the data in the open sea.

From the informations concerning the vertical distribution of tunas (HATTORI (1958), INOUE (1965), NISHIMURA et al. (1966)), it has been considered more reasonable to discuss the relation between the distribution of tunas and water types than that between tunas and water masses at specific depth. Here, a water type is defined as the group of the same type of T–Cl diagrams which are considered to show the same mixing stage of each water mass from surface to about 500 m depth.

Thus the relation between the distribution of tunas and water type in the Indian Ocean and the Western Pacific Ocean were reported by YAMANAKA, ANRAKU (1959, 1961, 1962). In this report, the same discussion is made for the North and South Pacific.

The source of oceanographic data are as follows; the data of tuna fishing grounds which were collected from 1949 to 1964 by the Japanese research vessels of national and prefectural government; the data of the SHUNYO MARU and the SHOYO MARU, research vessels of the Nankai Regional Fisheries Research Laboratory (1949~'65); the Imperial Japanese Navy Hydrographic Department (1935~'41), POFI (present HBL, 1949~'58), NORPAC (1955), EQUAPAC (1956), IGY (1957~'58), CSIRO (from 1957 onward), Institut Français D'Océanie (from 1956 onward), CCOFI (a portion), the data published in the IGY World Data Center A, part IIa, IIb Pacific Ocean. In the Eastern Pacific Ocean, where the data are rather scarce, those of the SHOYO MARU (1962~'64) and of IATTC were adopted.

I. Classification of the water types

Fig. 1 represents schematically each water type, and Fig. 2 shows the dia-

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grammatic distribution of water types in winter and summer seasons. T-Cl curves in a deep portion of each water type lie along the averaged curves of the water masses, I. W. (Intermediate Water), S. P. W. (Subarctic Pacific Water), W. N. P. C. W. (Western North Pacific Central Water), E. N. P. C. W. (Eastern North Pacific Central Water), P. E. W. (Pacific Equatorial Water), W. S. P. C. W. (Western South Pacific Central Water), E. S. P. C. W. (Eastern South Pacific Central Water), S. W. (Subantarctic Water), etc. after definition of SVERDRUP et al. (1952).

The explanation of water types for Fig. 1 a were made by YAMANAKA, ANRAKU

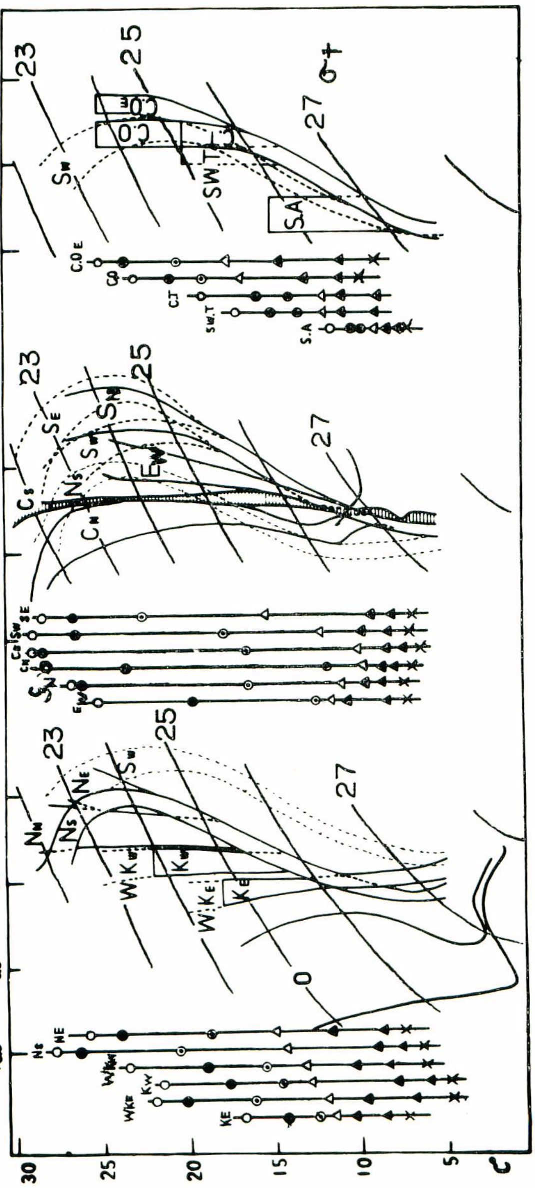

Fig. 1, a
Water types in the northwestern Pacific (the left side), the western part of the equatorial Pacific (the center) and the southwestern Pacific (the right side).

(1962), those for Fig. 1b and 1c are as following:

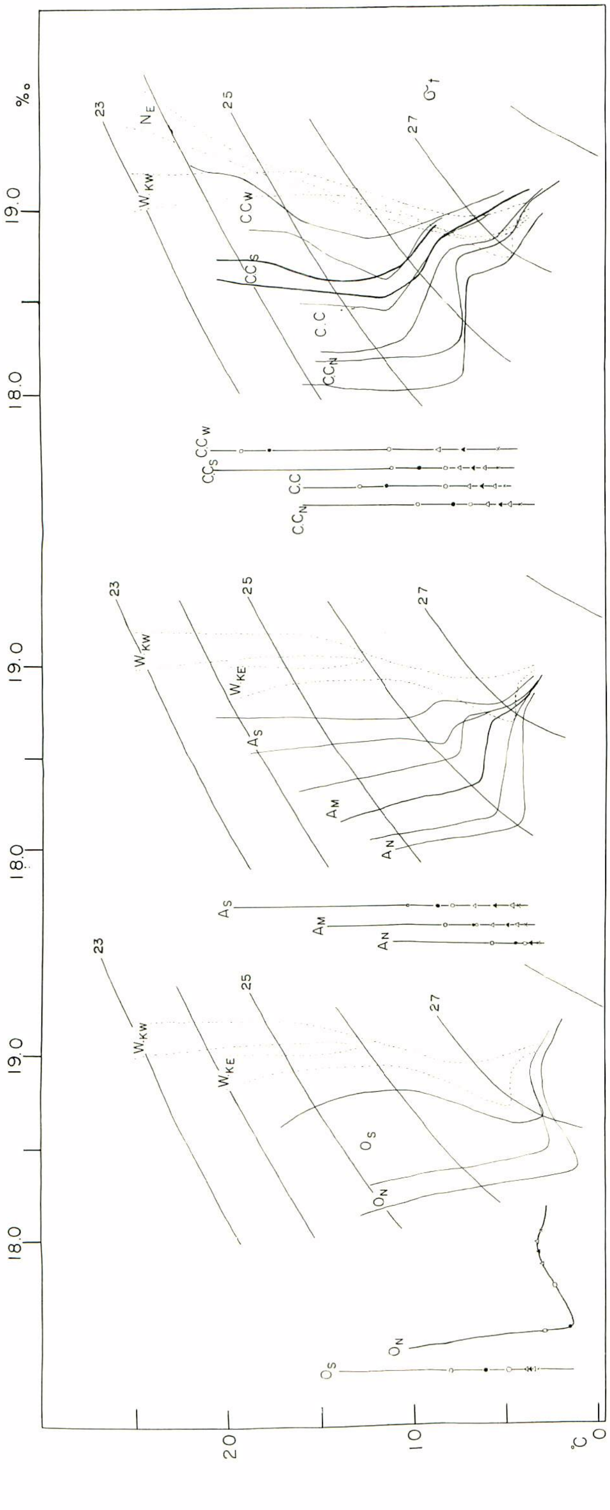

Fig. 1, b

Water types in the northern Pacific, around the Kuril Islands (the left side), around the Aleutian Islands (the center) and off the coast of the North America (the right side.)

Series O…O_N and O_S are characteristic types under the influence of the

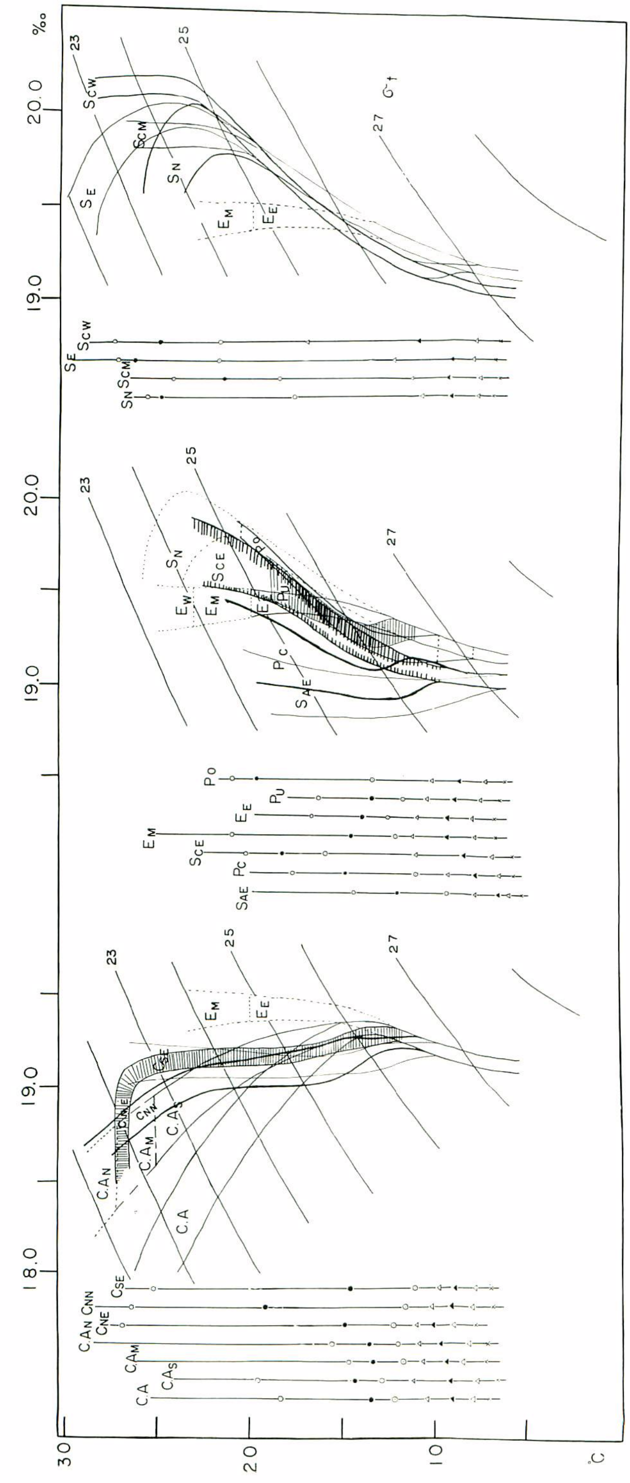

Fig. 1, c

Water types in the northeastern Pacific and the eastern part of the equatorial Pacific (the left side) and the southeastern Pacific (the center and the right side).

Fig. 1

Schematic representation of each water types of the North and South Pacific Ocean. sign in the figure indicate mean depth of each water types

○…50m, ●…100m, ⊙…200m, △…300m, ▲…400m, ⚠…500m, ×…600m

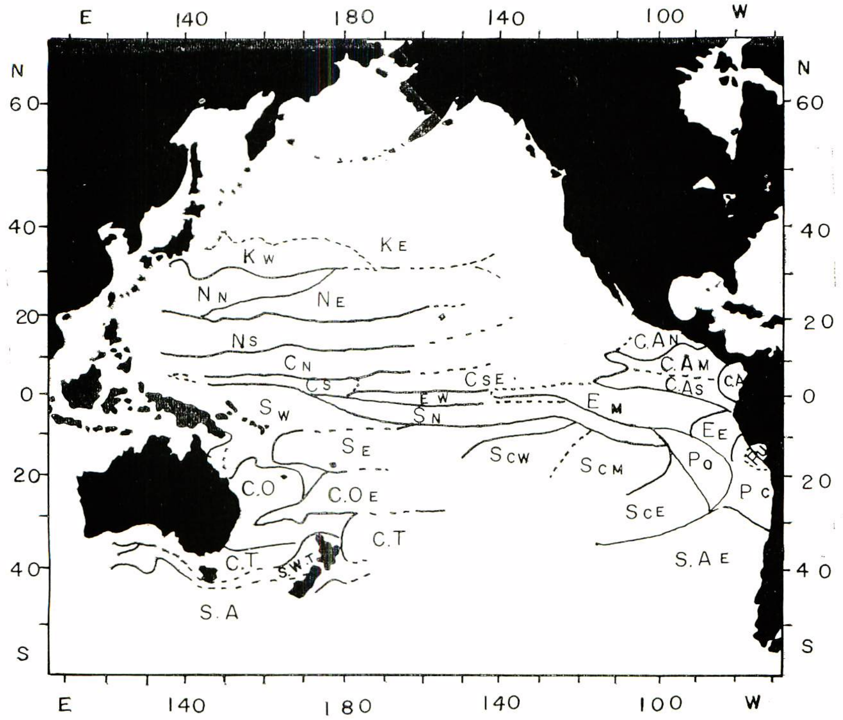

Fig. 2, a Northern Winter

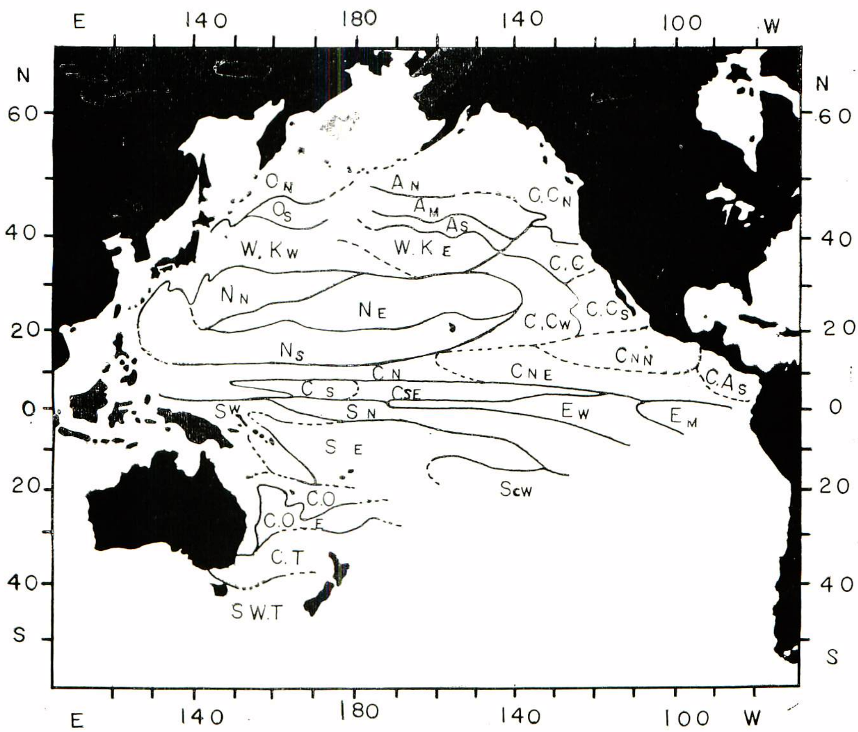

Fig. 2, b Northern Summer

Fig. 2 Diagrammatic distribution of water types in winter and summer season.

Oyashio Current. T-Cl pattern of Os correspond with that of the Oyashio front in August, which were studied by KAWAI (1955). T-Cl pattern of ON roughly corresponds with that of the southern Bering Sea, as been studied by MISHIMA, NISHIZAWA (1955).

Series A…This seems to be influenced by the Aleutian Current rather than by the Oyashio Current. AN, AM and AS correspond with the subantarctic, transition and subtropic waters respectively, as been studied by HIDA (1957). DODIMEAD et al. (1963) has classified T-S curves into four "envelopes", at the area between 45°~60°N, east of 175°E. Envelope 1~3 and envelope 4 roughly correspond with series O and series A, respectively.

Series C. C…This is a type under the influence of the California Current, and C. Cw correspond with the type of the California Current Extention, as been stated by SVERDRUP and FLEMING (1941).

Series C…This is a characteristic type of the Equatorial Counter Current, as been studied by YAMANAKA, ANRAKU (1962). CN~CNE and CS~CSE distribute at the northern and southern parts of the Counter Current, respectively. CNE and CSE seem to be modified by the other water type in the east.

Series C. A (Central America)…This seems to be closely related with the specific district rather than by current. It has low surface chrolinity (18.0 ‰), and distributes at the area of the Gulf of Panama in winter. These result correspond with the seasonal distribution of the surface salinity (BENNETT (1966)).

Series E…This is a characteristic type of the Equatorial Pacific Water as been defined by SVERDRUP et al. (1952). The character of this series changes gradually from EE to EW in accordance with change of properties of the sea water along the equator, which were studied by AUSTIN (1958).

Series S…This is a type related with the South Equatorial Current. Although SN were formerly named as ES in the report by YAMANAKA, ANRAKU (1962), T-Cl relation of this type has a close relation with that of series S rather than series E, it was named as SN in this report. SCN, SCS and SCE are situated at the north, south and east of the central part of the South Equatorial Current. Because of scarcity of data, the boundaries of distribution of each water type are unclear.

Series S. A…This is a type closely related with the Subantarctic Water, which was studied by YAMANAKA, ANRAKU (1962). S. AE distributes at the eastern part of the South Pacific.

Series P…This is a type related with the Peru Current. WYRTKI (1963) showed the T-S diagrams each of six different currents, and grouped them into two surface and two subsurface water masses based on the data of the STEP 1 Expedition. WYRTKI (1966) also discussed about the three surface and one subsurface water masses in the eastern Pacific Ocean. PU, PC and PO are characteristic types of the Peru Undercurrent, Peru Coastal Current and Peru Oceanic Current, respectively, which were studied by WYRTKI (1963).

II. Relation between the distribution of water types and the current

Fig. 2 indicates;

1. In the equatorial region, the western margin of water type Ew and EM stretches to the west in winter season and contracts to the east in summer season in accordance with the development and decay of the equatorial cold water bands.
2. In the Eastern Pacific Ocean, opposite result to that of WYRTKI (1965) is shown between the pattern of the distribution of water types in both seasons and that of oceanic circulation.

III. Relation between the distribution of water types and the distribution of tunas

1). General relation

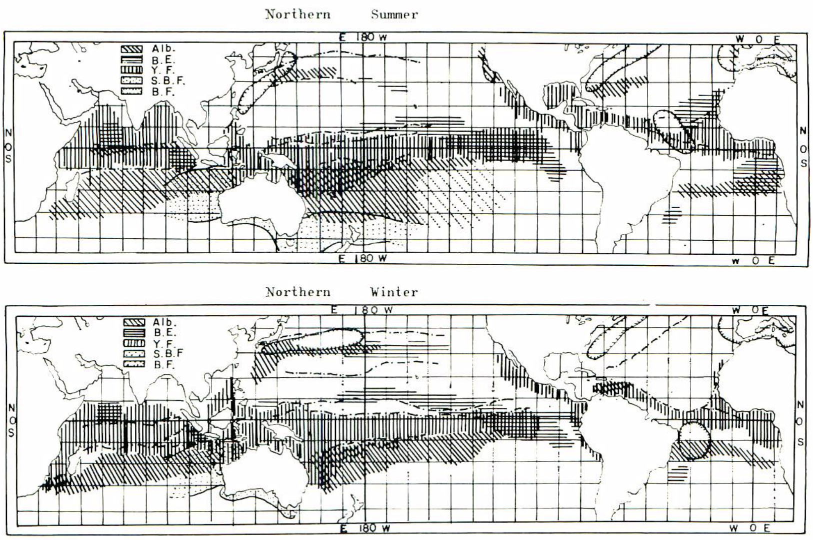

Fig. 3 Diagrammatic distribution of the fishing ground of tunas and the boundary of the ocean current in the Pacific Oceans.
Alb ···Albacore, B. E.···Bigeye
Y. F.···Yellowfin, S. B. F.···Southern Bluefin
B. F.···Bluefin

Fig. 3 shows diagrammatic distribution of tunas and the boundary of the ocean current in the Pacific Ocean. From Fig. 2 and Fig. 3, a relation between the distribution of water types and the distribution and migration of tunas in the North and South Pacific were discussed by species of tunas.

a) Yellowfin:

1. The yellowfin distributes in the water types C~E~S in the equatorial region, while in C. Cs, CNN and C. A, in the coastal region of the North and South America.

2. In the eastern Equatorial Pacific, two isolated distributions are found in the north and south in winter season, but this discontinuity become unclear in summer season (KAMIMURA, HONMA (1963)). These phenomena correspond to the expansion and contraction of the water types Ew, EM as previously mentioned.

3. Concerning the relation between the distribution of water type and the migration in accordance with the growth in the Equatorial Pacific, which was studied by KAMIMURA, HONMA (1963), the following matters can be said.

(a) It distributes in Sw, SE, water of high temperature and high chrolinity in young stage (less than 120 cm F. L.).

(b) As it grows, it moves from Sw to Ew and EM, the waters of low temperature and low chrolinity.

(c) Then, it returns back to CSE, Ew, SN.

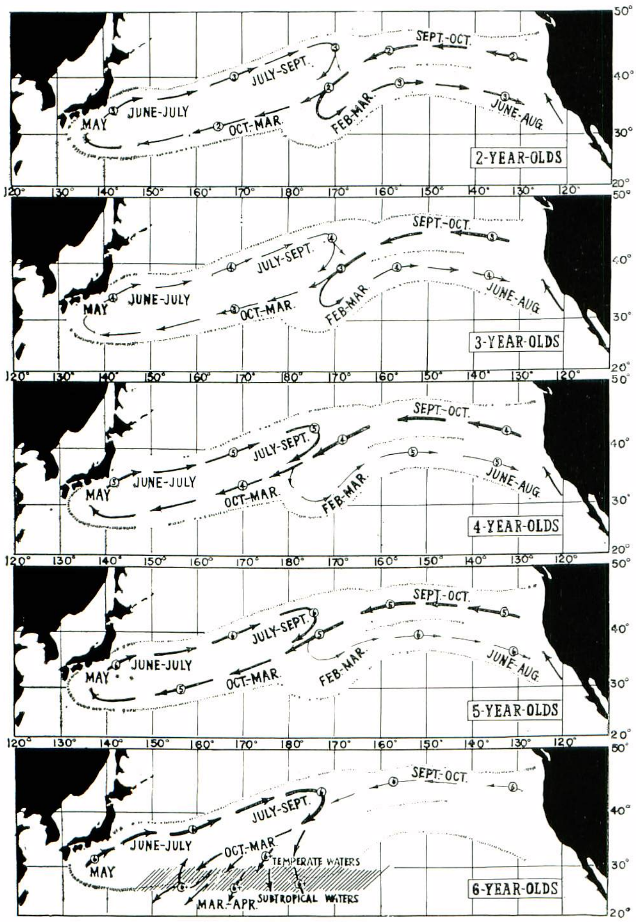

Fig. 4 Model of albacore migrations in the North Pacific Ocean by age groups (ages encircled) (OTSU and UCHIDA (1963)).

4. In the coastal region of the North and South America, young group (less than 120 cm F. L.) distributes in C. A and C. Cs, waters of low chrolinity (JOSEPH et al. (1964)).

In the equatorial region, young group also distribute in Sw, SE as above mentioned. These facts seems to support UEYANAGI (1966), who postulates that both groups seems to be indepependent population unit.

b) Bigeye:

In the Western Pacific, two distribution centers in KE and CN are segregated by series N, each of which corresponds to different ecological stage, namely feeding and spawning. The centers of distribution of the yellowfin in series S and Cs are segregated from that of the

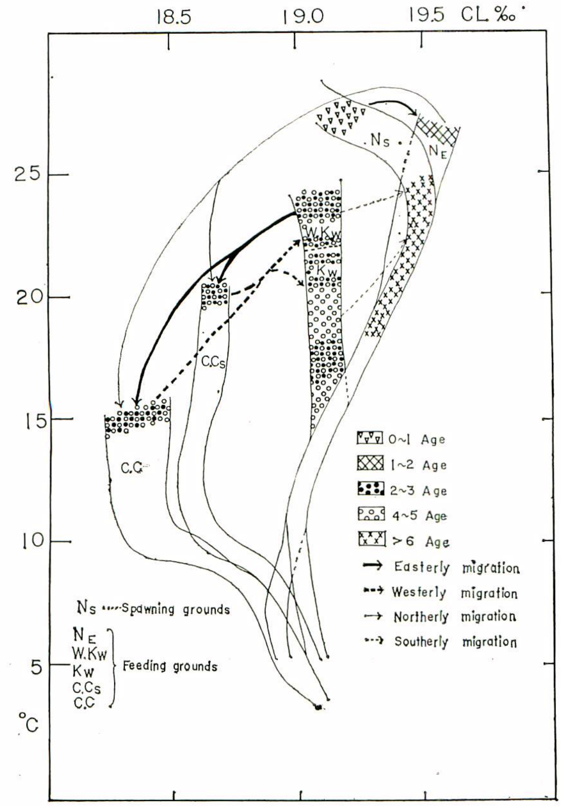

Fig. 5 Schematic representation of the relation between the distribution of water types and model of albacore migration in the North Pacific Ocean.

bigeye (YAMANAKA, ANRAKU (1962)). But, in the east, the distribution extends continuously to the south, that is to say, from CN, CNE to CSE, EW and EM until it overlaps with that of the yellowfin.

Comparing the water type patterns to distribution of tunas with consideration of the size composition and the distribution of spawning group in the equatorial region (KUME, SHIOHAMA (1965), KIKAWA (1966)), the following can be said.

1. Small fishes distribute in each of water types, namely CN, CNE, CSE, EW, EM.
2. The center of distribution of middle and large fish as well as the spawning group shifts gradually to the water type EM of high chrolinity according to the growth.
3. The reason of the southward shift of distribution center, and the overlap with that of yellowfin in the eastern area is still unexplained.

c) **Albacore:**

Fig. 5 shows the relation between the distribution of water types and schematic albacore migration in the North Pacific Ocean (Fig. 4) by OTSU and UCHIDA (1963). Fig. 4 and 5 indicate that;

1. The center of distribution of albacore lies in different water types according to the ecological stage.
2. The T-Cl pattern of the water type in which the young fish under 2 age distribute widely differs from that of the elder ones, while the difference decreases during the feeding stage of 2 age to 5 age, and much less between feeding and spawning stages.

d) **Bluefin:**

Fig. 6 shows diagrammatically the relation between the water types and the distribution and migration of bluefin in the North Pacific Ocean (NAKAMURA (1965), FLITTNER (1966), YAMANAKA (unpublished)).

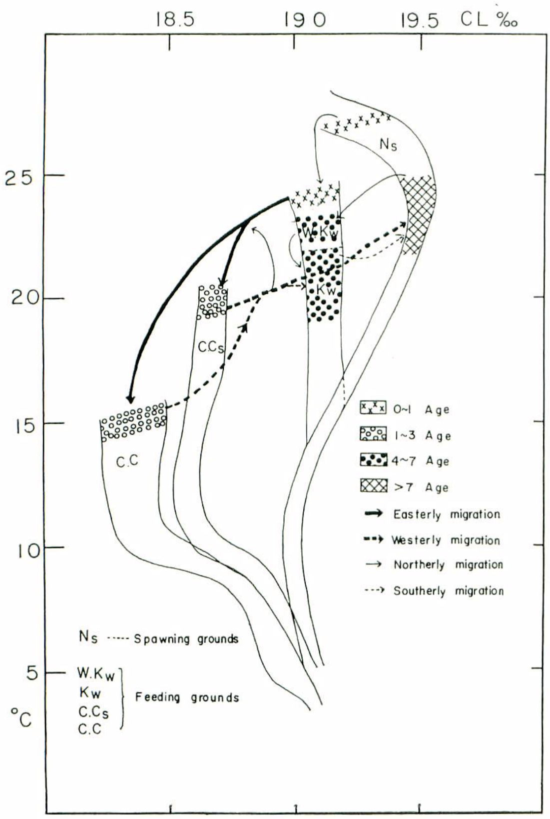

Fig. 6 Schematic representation of the relation between the distribution of water types and the distribution and migration of bluefin.

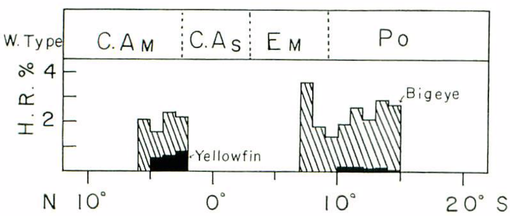

Fig. 7, a December, 1960 by the HORIZON.

The following can be said.

1. The bluefin makes an easterly transpacific migration in young stage, from 0 age to under 2 age, while it does an westerly one from 3 age to 4 age, respectively. In that case, variation of temperature and chrolinity of water type Kw differs widely from C. C.
2. Among the various tunas, the segregation of distribution by water types in accordance with the ecological stage is the clearest in case of the bluefin.

II). Relation in the Eastern Pacific Ocean

Informations are particularly scare in this region, and only data available came from the SHOYO MARU (1962~'65), STEP-1 Expedition (1960); and IATTC (SUDA, SCHAEFER (1965), KUME, SCHAEFER (1966) and FORSBERG, BROENKOW (1965)). Fig. 7 shows diagrammatically the relation between the distribution of tunas and that of water types along 95°W longitude. Fig. 8 shows the relation between the results of investigation by tuna long-line gear and the distribution of water types by the SHOYO MARU in the East-

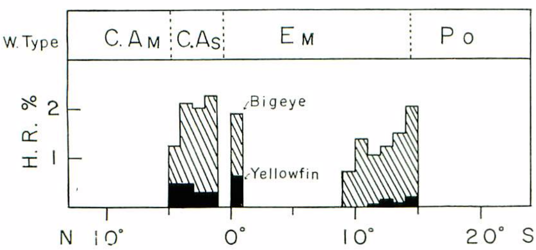

Fig. 7, b From December, 1962 through January, 1963 by the SHOYO MARU.

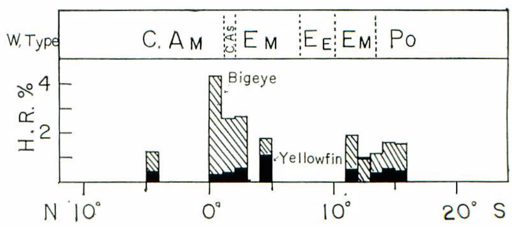

Fig. 7, c From December, 1963 through January, 1964 by the SHOYO MARU.

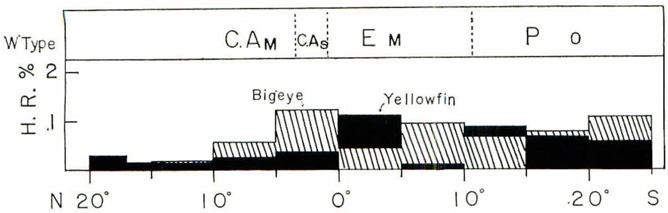

Fig. 7, d From December, 1964 through January, 1965 by the SHOYO MARU.

Fig. 7 Diagrammatic representation of the relation between the distribution of tunas and that of water types along 95°W longtude.

Hooking rate means average hooking rate per grid of 1 degree latitude and 10 degree longitued.

ern Pacific Ocean. Some of the findings were as follows:

1. The bigeye distubutes certainly in the region of C. AS and in the southern part of C. AM in the equatorial region, and it shifts accompanying with them.
2. The bigeye also distributes in the northern and southern parts of EM and region of PO, but does not in the region of EE.
3. Density of the distribution of yellowfin seems high at the region of C. AN west of 110°W and C. AM north of 10°N, with a decling trend toward the east.
4. Small and immature albacores distributes in S. AE and PC. While, middle and large ones do in SCW, SCE, thus indicating that the distribution of albacore is segregated by the water types according to the ecological stages.

V. Discussion

1). Classification of water type

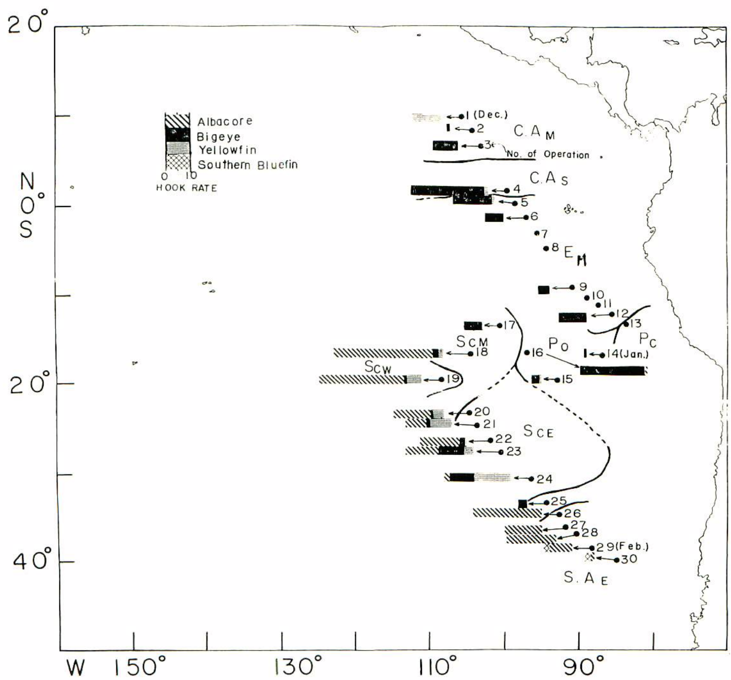

Fig. 8, a From December, 1962 through January, 1963 by the SHOYO MARU.

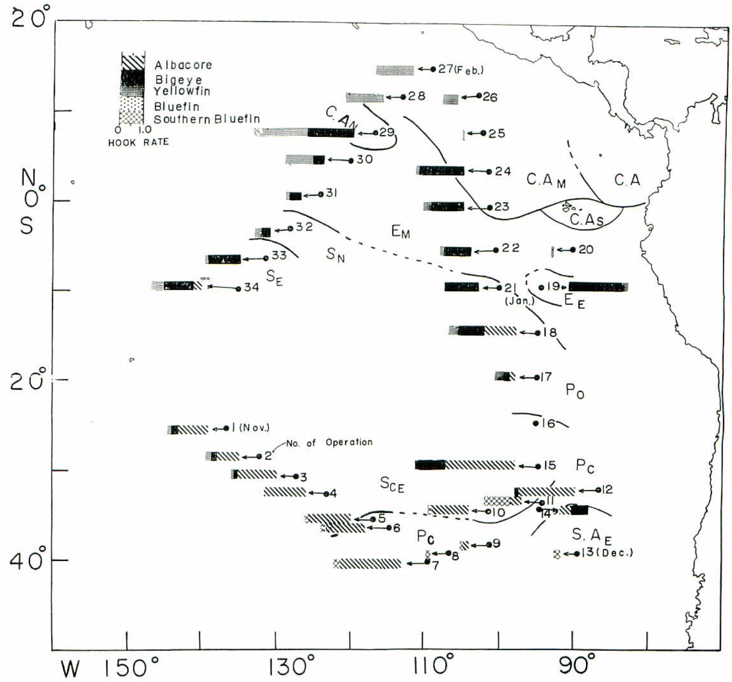

Fig. 8, b From December, 1963 through January, 1964 by the SHOYO MARU.

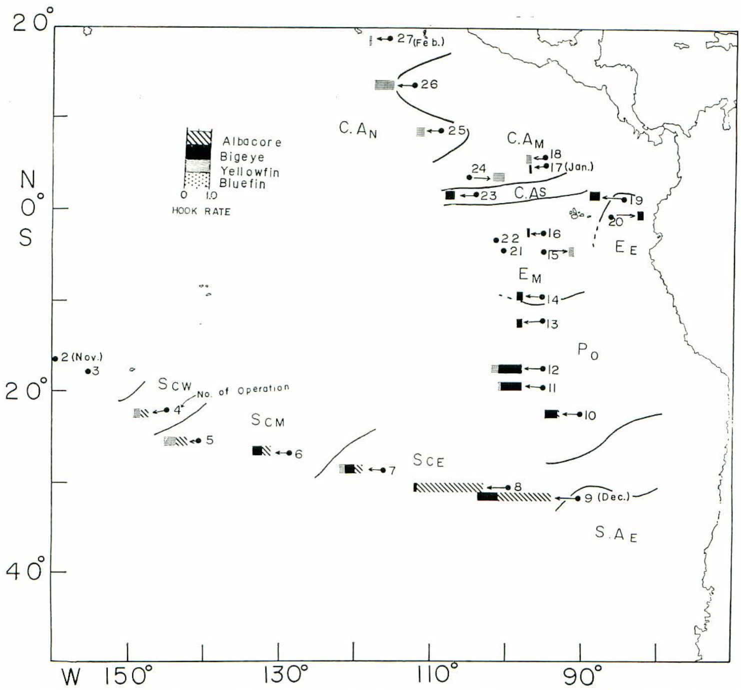

Fig. 8, c From December, 1963 through January, 1964 by the SHOYO MARU.

Fig. 8 Relation between the results of investigation by tuna long-line gear and the distribution of water types by the SHOYO MARU in the Eastern Pacific Ocean.

It was criticized at the Pacific Tuna Biology Conference in 1961 that there needs some means of portraying T-S relationship as a single index of water type on a timespace basis, and an approach worth considering would be the use of discriminant function analysis. However, it can be noticed that T-Cl curves for the surface water, although they have a certain range, can be practically classified into same types as in the case of upper waters, when the oceanographic data of the open sea are used. If more data would be available, it would be able to classify the water types in more detail by the season conforming to the oceanic circulation pattern. Valuable as it is, in the oceanographic study, to discuss the distribution of water masses by season and specific depth basing upon their conservative properties, it should also be necessary to consider the information of swimming layer obtained by the fish finder (HATTORI (1958), INOUE (1965), NISHIMURA et al. (1966)), when the water mass is discussed in relate to the distribution of tunas.

2). **Significance of the T-Cl character for the distribution of tunas**

KAWASAKI (1958) postulated that salinity is one of the important environmental factor from the point of osmotic balance. SAKAMOTO (1962) postulated that the T-Cl, as a complex, may be taken as a new physicochemical factor, and it works directly on the physiological mechanism of fish school under the condition in which their environment selectivity can be kept normally. On the contrary, BLACKBURN (1965) stated that salinity *per se* has no known direct effect on tuna distribution either at or between it range limits, and that it would be premature to assert that there is any real causal relationship between distribution of water masses and that of tuna species.

The author's principle hitherto has been that centers of distribution of each species of tuna are segregated by water types. However, this principle was found inconsistent because of the discovery of a transpacific migration of tuna. In this report, the principle that centers of the distribution of tnnas are segregated by water types according to the ecological stage were submitted. As previously mentioned, the principles is applicable only to the bluefin and the albacore, but not for the yellowfin and bigeye. The authors are aware that some substantial consideration just like BLACKBURN (1965) pointed out, are required to explain the inconsistency between the case of bluefin and the albacore and that of the yellowfin and the bigeye.

3). **Future problem**

In the mid-Pacific and the Eastern Pacific, a relation between the basic productivity, phytoplankton, zooplankton and tunas were discussed (CROMWELL (1953), KING and DEMOND (1953), SETTE(1955), WOOSTER and JENNING (1955), KING and HIDA (1957), BLACKBURN (1961)). However, many discrepancies are seen between abovementioned relationships and sometimes the relation which stands in the yellowfin does not do in the case of bigeye (YAMANAKA (1962), KAMIMURA, HONMA (1962), BLACKBURN (1965), YAMANAKA (1961)).

Reasons of the overlap of the distribution for yellowfin and bigeye in the mid-Pacific and Eastern Pacific can not be explained in either case of postulate from current system, water type and basic productivity as previously mentioned. Accordingly, in future work, vertical and horizontal distribution of tunas must be discussed synthetically from many aspects, namely thermocline topography, phycnocline, basic productivity etc..

Concerning to the overlap of the distribution for yellowfin and bigeye, following postulates are submitted by SUDA et al. (1969).

If the habitats of yellowfin and bigeye were postulated in the tropic surface water above and in the thermocline respectively, the overlap of the distribution for two species might be illustrated as the change of availability of bigeye for tuna long-line gear.

In promoting above discussion, information by the fish finder will greatly contribute to the study of vertical and horizontal distribution of tunas in relation to the environmental conditions, and to verifry the postulate of SUDA et al. (1969).

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南北太平洋におけるマグロ類の分布とWater Type の分布

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要旨　マグロ類の分布と海流系との間に密接な関連のあることは，既に中村，山中（1959）によって報告されているが，その後，筆者等はさらに，前述の関係を立入って吟味する目的でこの研究を進めた。最近の魚群探知機による知見から，マグロ類の中には 500 m 深までに分布するものがあることが知られている。そこで，冬，夏期別に，0～500 m 深までの各層の水塊の層重状態が同じような海域を，T-Cl diagram のタイプによって区分し，ここではこれを Water Type と名づけ，これの意義や，この分布とマグロ類の分布との関係等について検討した。クロマグロ，ビンナガは成長の過程により，あるいは生態別に分布する Water Type を異にしていると云うことができるが，キハダ，メバチでは，その関係は前者の場合ほど明瞭ではない。特に，中部～東部太平洋の赤道海域において，キハダとメバチの分布域が重なる理由については，今のところ Water Type の面から説明することは困難であり，また海流系や海洋の基礎的生産力の面からも説明出来ない。したがって，これについては，マグロ類の水平的な分布だけでなく，鉛直的な分布と海洋構造の面から吟味する必要があろう。