A CONTRIBUTION TO THE KNOWLEDGE OF THE STRUCTURE AND COMPOSITION OF THE WATER MASSES OFF EASTERN PHILIPPINES

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FOUR TEXT FIGURES

The water masses found in the Eastern Philippines have been classified into three distinct bodies based on temperature-salinity relationship, namely, the Western North Pacific Central, water, the Pacific Equatorial water, and the North Pacific Intermediate water. However, the North Pacific Intermediate water mass has been excluded from this analysis because its temperature-salinity relationships are not as clear cut as those of the first two and its position in the water column is such that it vitiates the determination of percentage composition.

The westerly North Pacific Equatorial Current carries these water masses into the waterways and inland seas of the Philippines, either directly or indirectly through the South China Sea to the west or the Celebes Sea to the South. An analysis then of the structure and composition of these water masses prior to their entry into the fishing areas of the Philippines will fill the need for understanding the physical factors that define the normal patterns of marine ecology of these fishing grounds. The importance of this knowledge is, therefore, fundamental to fisheries investigations in the Philippines.

SOURCE OF DATA

The analysis presented in this report has been made possible with the free use of the *Spencer F. Baird* data collected in 1947–50 by the United States Fish and Wildlife Service. It was the plan in the beginning to include temperature and salinity data from other sources, principally those collected from the same or adjacent areas by Japanese research ships. But after examination of these observations, a great number of the salinities disclosed discrepancies which could not be explained. Observations made by other investigators are either too few or unavailable. The *Baird* data, however, have been found to be amply sufficient for the purposes of this analysis.

METHODS

The temperature-salinity diagram method, first introduced by Helland-Hansen (1918) and later extensively used by others in separating and characterizing the water masses in the sea, has proved to be a valuable aid in oceanography. The T–S diagram itself serves as a means for identifying the physical properties of a given water mass and tracing its origin and transformation by physical processes. It affords a quick survey of stability conditions within the water column (Jacobsen, 1929). Finally, it discloses intrinsic evidences of probable error of observation and transposition of data (Parr, 1935).

The T–S diagram is in reality a graphical representation of temperature and salinity on a rectangular coordinate system in relation to two parameters, namely, depth and time (Stockman, 1946). When thus plotted, corresponding temperature and salinity values for any given time arrange themselves according to depth. This singular arrangement of the points into a well-defined curve distinguishes one water mass from another.

On the basis of the T–S relations of the principal water masses of the oceans (Sverdrup, 1943), the Western North Pacific Central water and the Pacific Equatorial water may be defined by their salinities at stated temperatures as follows:

Western North Pacific Central Water

10°	12°	14°	16°
34.24±0.07	34.38±0.06	34.52±0.06	34.67±0.07

Pacific Equatorial Water

6°	8°	10°	12°	14°
34.56±0.05	34.60±0.05	34.72±0.07	34.86±0.06	35.05±0.06

These values were plotted as narrow bands in text fig. 4; in text fig. 1 only the mean salinities were paired with the temperatures. On account of the fact that both water masses are found at depths to which seasonal changes may no longer be effective, their T–S curves may be used in this analysis irrespective of the seasons.

A convenient and effective method for determining the composition of varying mixtures of the two water masses is graphically presented in text fig. 1. This method is an adoption of a similar scheme introduced at the Scripps Institution of Oceanography for determining the percentage composition of the two water masses found off Western California. The two bold lines drawn on each side of the measuring scale were derived, as has already been mentioned in the beginning, from

the curves drawn by Sverdrup (1943). That on the left side represents the mean curve of the temperature-salinity relationships of the Western North Pacific Central water, while that on the other side those of Pacific Equatorial water. In the area of transition enclosed by the two boundary curves, lines

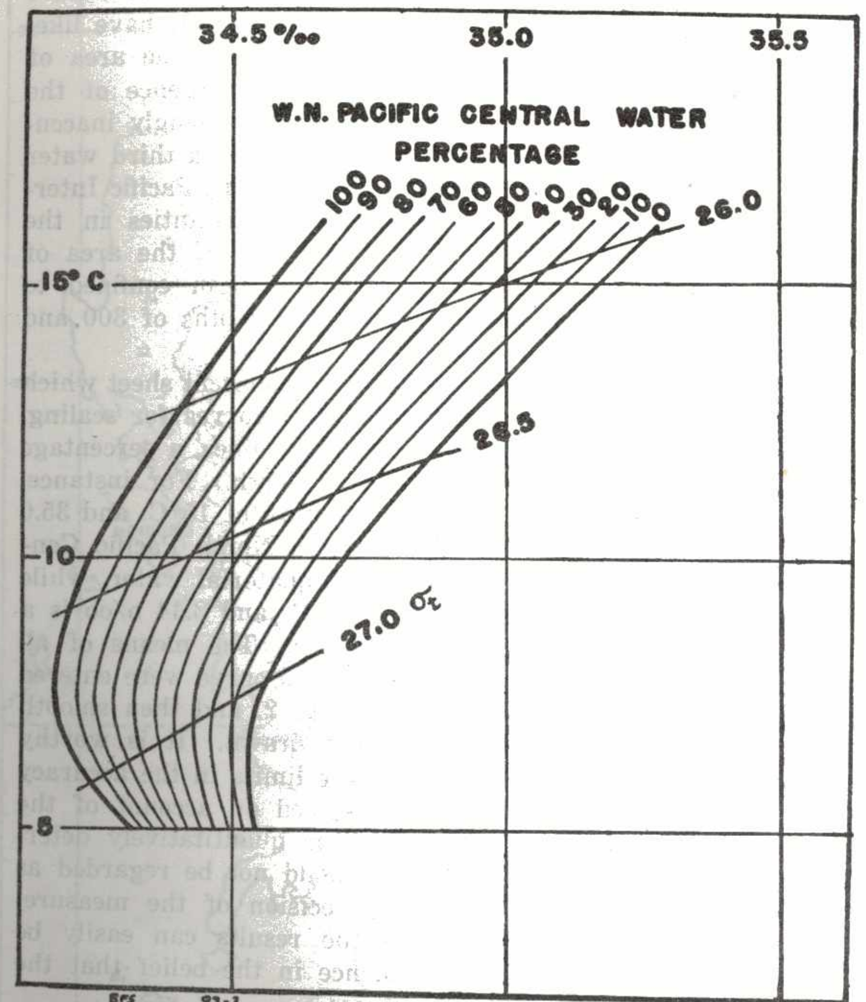

FIG. 1. Showing the measuring scale used in determining percentage composition.

corresponding to percental proportions of the water masses were drawn. The spacing was based on the isopycnals which were entered to indicate the probable paths along which lateral mixing is assumed to take place. These isopycnals were referred to the pressure of one atmosphere and were thus labelled as sigma-t surfaces, which are here assumed to depart insignificantly from the true isentropic surfaces. The temperatures, however, were not referred to the same pressure as very little advantage could be gained thereby for the purposes of this work.

The temperature and salinity relationships of the surface layers are of little physical significance and, therefore, have been excluded from the analysis. The lower layers have likewise been omitted for two reasons. Firstly, as the area of transition narrows down to the point of convergence of the two boundary curves, the scaling becomes increasingly inaccurate and, secondly, the effects of the presence of a third water mass, already referred to previously as the North Pacific Intermediate water, will naturally introduce uncertainties in the percentage values scaled from the lower part of the area of transition. Consequently, the analysis has been confined to that part of the water column between the depths of 300 and 600 meters.

The measuring scale was drawn on a transparent sheet which was superimposed upon the individual T–S curves for scaling. For every pair of temperature and salinity values, a percentage value was read off from each standard depth. For instance, at a certain standard depth a water mixture of 15°C. and 35.0 o/oo contains about 28 per cent Western North Pacific Central water and 72 per cent of Pacific Equatorial water, while at another standard depth water of 10°C. and 3.44 o/oo is a 50–50 mixture of the two water masses. The means of all the values thus scaled from each individual curve were entered on the horizontal plan shown in text fig. 2, and then smooth lines connecting the same values were drawn. It is worthy to mention at this point that no definite limits in the accuracy of the scaled percentages can be assigned on account of the many factors involved which cannot be quantitatively determined. Therefore, the percentages should not be regarded as representing absolute values. The precision of the measurements is, however, remarkable as the results can easily be reproduced. Hence, there is confidence in the belief that the results have a fair relative correctness.

DISCUSSION OF RESULTS

It is readily seen from text fig. 2 that the percentage composition of the mixture of the two water masses rather regularly increases northward with respect to the Western North Pacific Central water. The somewhat complex picture seen in the

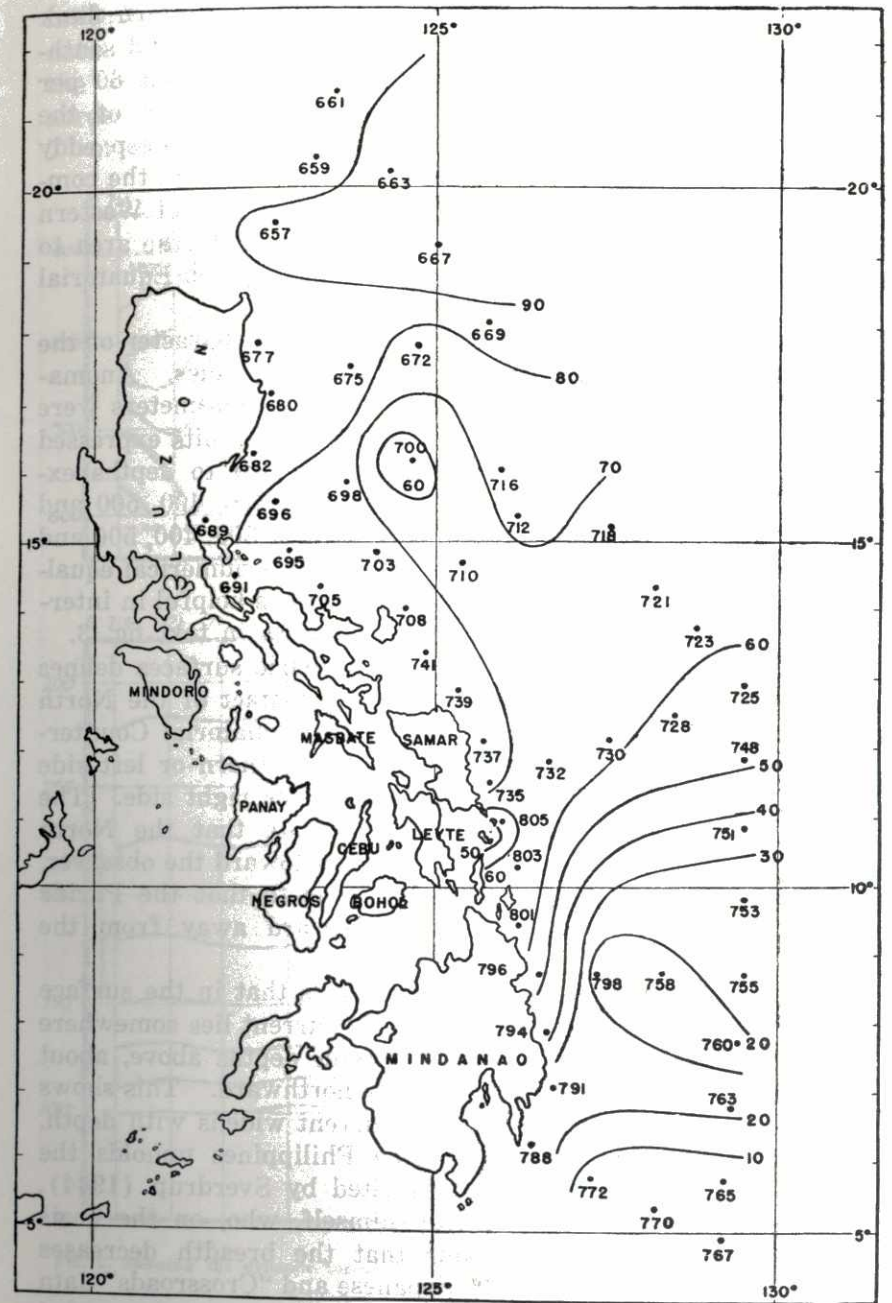

FIG. 2. Showing the percentage composition of the waters off eastern Philippines with respect to the Wester North Pacific Central water and the Pacific Equatorial water.

vicinity of the 10° N. latitude suggests the effects of the great North Pacific Equatorial Current, as it hits the eastern flank of the Philippines which divides it into its northern and southern components. The small pocket of water of about 60 per cent in composition located east of Luzon and north of the 15° N. latitude presumably represents a broad and deep eddy at the surface. In the area to the northeast of Luzon the composition of the water mixture is close to 90 per cent of Western North Pacific Central water which, with respect to the area to the southeast of Mindanao, is represented by Pacific Equatorial water.

Text fig. 3 discloses interesting details of the character of the two current systems dominating Eastern Philippines. Anomalies of dynamic heights expressed in dynamic centimeters were referred to the 2,000-decibar surface. Pressure units expressed in decibars may be taken as numerically equal to depths expressed in linear meters. Thus, pressures of 300, 400, 500 and 600 decibars correspond to geometric depths of 300, 400, 500 and 600 meters, respectively. A knowledge of this numerical equality between two entirely different dimensions is helpful in interpreting the pictures delineated by the profiles in text fig. 3.

The curve shown cutting across the isobaric surfaces defines approximately the position of the line of contact of the North Pacific Equatorial Current and the Pacific Equatorial Counter-Current. The first is represented on the northern or left side of the line and the second on the southern or right side. The rising isobaric surfaces to the left indicate that the North Pacific Equatorial Current flows westward toward the observer, while those to the right of the line indicate that the Pacific Equatorial Counter-Current moves eastward away from the observer.

The upper profile in fig. 3 further shows that in the surface layers the southern edge of the westerly current lies somewhere between B–760 and B–763, but at greater depths above, about 400 meters, it is displaced progressively northward. This shows that the Pacific Equatorial Counter-Current widens with depth. The fact that this is so in Eastern Philippines upholds the views of Defant and Krummel, as cited by Sverdrup (1944), but contradicts those of Sverdrup himself, who, on the basis of the Carnegie data, maintains that the breadth decreases with depth. In this respect the Japanese and "Crossroads" data of the Marshall Islands area presented by Barnes, Bumpus, and Lyman (1948) corroborate the Carnegie data collected south-

east and southwest of the Hawaiian Islands at about the same latitude as that for the *Baird*, the Japanese and "Crossroads" data. This fact appears to indicate that the boundary between the west and east-setting currents is maintained latitudinally across the Pacific Ocean. It appears to be approximately at 7° or 8° N. latitude.

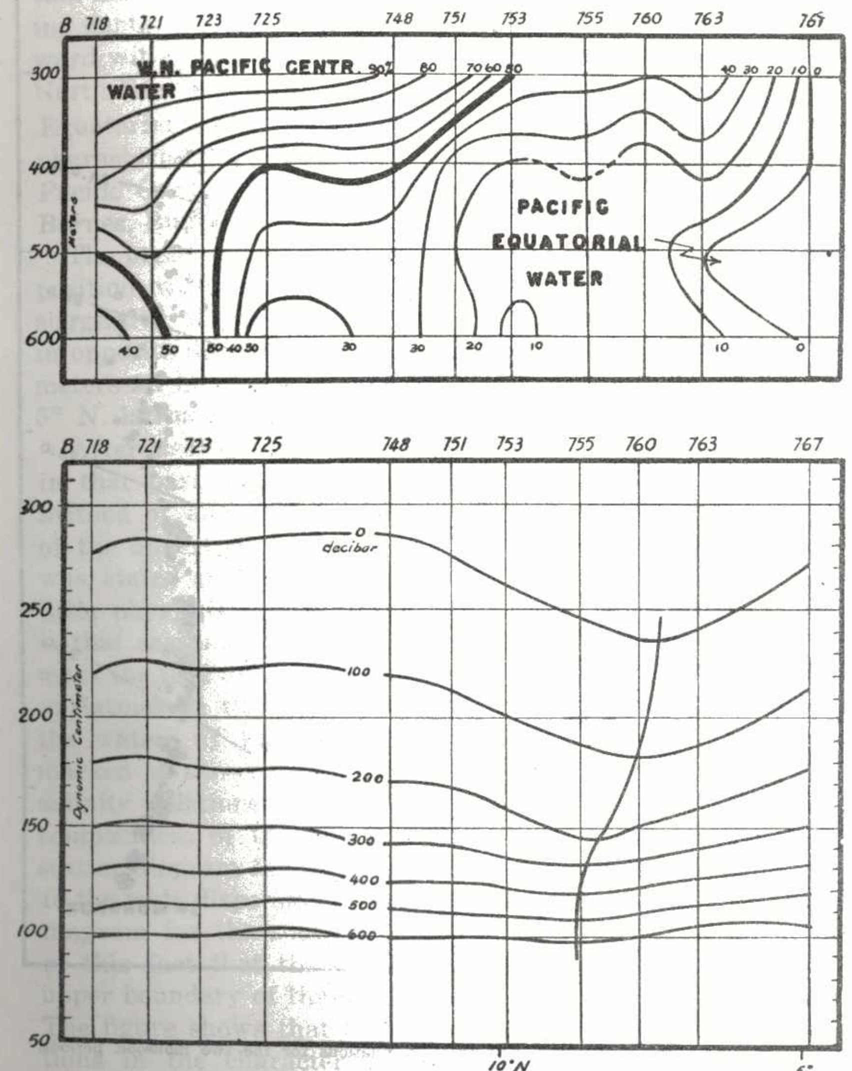

FIG. 3. Showing the dynamic topography and the percentage composition in a vertical section.

As shown by the slopes of the four isobaric surfaces, the strength of both currents is greatly diminished beginning at 300 meters, the upper boundary of the water column considered

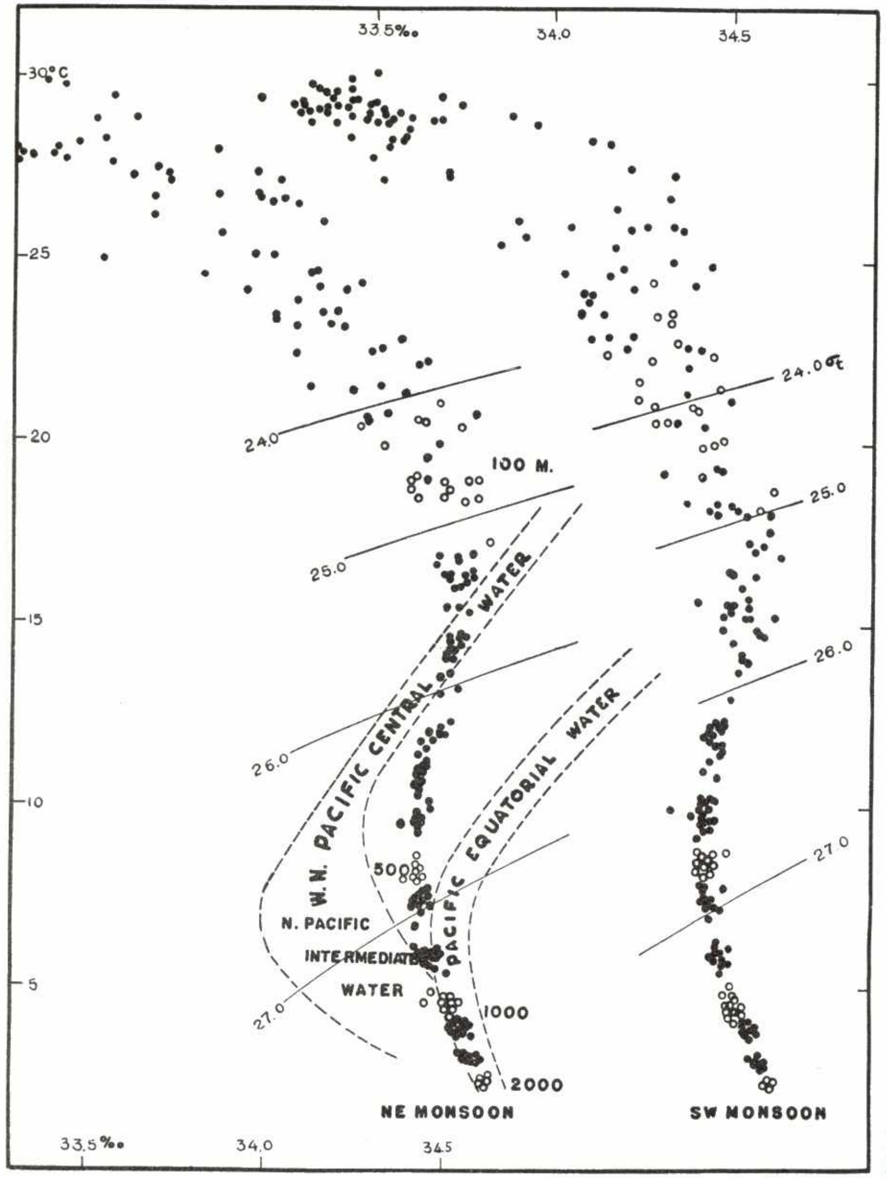

FIG. 4. Showing a composite picture of the T-S relations for the two monsoon periods.

in this analysis. The reverse slopes of the isobaric surfaces shown at the extreme left-hand side serve to confirm the statement made previously regarding the presence in the vicinity of that area of a large cyclonic eddy of great vertical extent.

The lower profile shows that while the percentage composition increases with increasing latitude it decreases with increasing depth. Essentially, this means that as one proceeds northward within the area covered by this work, the lighter Western North Pacific Central water increases in thickness as the Pacific Equatorial water sinks to greater depths. This seems to be a characteristic feature of the waters of the Western North Pacific Ocean where both kinds of water masses are present. Barnes, Bumpus, and Lyman (1948) reported the same feature.

The presence of a large body of water of nearly uniform composition within the area of contact of the two currents is suggestive of the churning action of the two currents moving in opposite directions. South of B–763 at about a depth of 500 meters an intrusion of the Pacific Equatorial water crosses the 5° N. latitude.

After dealing with the characteristics of the water masses in that part of the water column which easily lends to this method of analysis, it is now logical to turn to the structure of the upper part of the water column. In this connection, it was stated in the beginning that the surface layers were of little physical significance in this study. The reason for this is that seasonal variations and local effects tend to obscure or mask the true temperature and salinity relationships. Monsoonal variations in the physical properties of the surface layers of the waters of Eastern Philippines appear to be rather well-marked as shown in text fig. 4, which shows the temperature-salinity relationships during the two different seasons. The compactness of the points above the 25.0 sigma-t line in the scatter diagram for the northeast monsoon season is in contrast to the wide dispersion of the corresponding points in the scatter diagram for the southwest monsoon period. It is on account of this fact that the depth of 300 meters was chosen as the upper boundary of the water column considered in this analysis. The figure shows that below this depth the monsoonal fluctuations in the character of the surface layers are no longer effective.

A closer examination of the two scatter diagrams will reveal the fact that two significant layers of salinity maximum and salinity minimum are found within the entire water column.

The layer of salinity maximum appears to coincide with the 24.0 sigma-t line during the northeast monsoon period. During the other season this layer is also quite evident, but its position in relation to any isopycnal is not so clear-cut.

SUMMARY

The Western North Pacific Central Water increases in thickness with increasing latitude as the Pacific Equatorial Water sinks to greater depths. This trend is interrupted only by the presence of an eddy east of Luzon.

The Pacific Equatorial Current widens with depth in Eastern Philippines; the boundary between this current and the North Pacific Equatorial Current is maintained latitudinally at approximately 7° or 8° N.

A layer of salinity minimum is found below the subsurface layer of salinity maximum. The layer of salinity minimum has a salinity less than 34.5 o/oo and a temperature range of 5–10° C., while the other layer has a salinity greater than 35.0 o/oo and a temperature range of 20°–25°C.

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ILLUSTRATIONS

TEXT FIGURES