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Notes on the Peruvian coastal current. 1. An introduction to the ecology of Pisco Bay[1]

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Summary—Biological calamities of the Peruvian Coastal Current have long been associated with undue warming of the surface water. These high water temperatures have most frequently been attributed to an incursion of fresher water from the north (" El Niño "). More recently they have also been ascribed to the intrusion of wedges of saltier, warm offshore water and even to the discharge from local streams. Re-examination of the warming processes in Pisco Bay indicates that solar radiation probably accounts for a large proportion of the high temperatures observed there. Such warming can occur whenever upwelling, the only effective source of cooling, ceases for any appreciable period.

From available evidence, there appears to be an annual temperature range of about 7°C. Salinities of the current as a whole do not normally vary by as much as 2‰ whether the water be derived from upwelling, from offshore or from " El Niño." The ranges of these characteristics are much more limited than in some coastal waters and about the same as for others. The actual temperature limits are very nearly the same as for the cycle in the Mediterranean.

Consequently, before the relationship between temperature and the recurrent biological disasters can be understood, it is suggested that two peculiarities of the area should be studied in detail: (1) the process of upwelling which provides nutrient salts for the growth of phytoplankton and (2) the effect, if any, of that fraction of the birds' excreta dropped in the water on the nutrient cycle and on the character of the phytoplankton.

INTRODUCTION

The economic importance and abundance of the guano-producing birds have long focused attention on the peculiarly rich environment provided by the inshore waters of the Peruvian Coastal Current. Despite this, remarkably little is known of the seasonal or annual cycle of events which support such enormous populations there, because previous studies have been mostly incidental to other work. Thus, there are a few widely-spaced oceanographic stations forming part of more extensive surveys elsewhere[2] and surface observations from vessels traversing the area.[3] Time and facilities precluded detailed hydrographic and biological surveys from most fisheries programmes.[4]

More spectacular and more disturbing to the economy, however, are the recurrent periods when the water temperatures rise suddenly and the birds die of starvation by the thousands. Such events have most often been attributed to the encroachment of warm water from the north (" El Niño "). This is accompanied by torrential rains and northerly rather than southerly winds in northern Peru (Murphy, 1936; Schott, 1931; Zorell, 1928). In the Pisco area, on the other hand, there is shift in the winds from southeast to southwest (Vogt, 1942). During such periods, the anchovies are likely to disappear and the guano birds then desert their nests in search

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[1] Contribution No. 671 of the Woods Hole Oceanographic Institution.

[2] Agassiz, 1906; Discovery Committee, 1949; Fleming, *et al.*, 1945; Funder, 1916; Gunther, 1936, 1936a; Sverdrup, 1930, 1931; Scripps Institution of Oceanography, 1952; Wooster, 1952.

[3] Coker, 1918; Deutschen Seewarte, 1930; Murphy, 1923, 1925, 1926, 1936; Schott, 1931, 1932, 1952; Schweigger, 1942, 1942a, 1943, 1947, 1949, 1951, 1953; Zorell, 1928.

[4] Bini, 1952; Coker, 1908, 1908a, 1908b, 1908c; Fiedler, Jarvis and Lobell, 1943; Landa, 1953; Rojas, 1953.

of food. Some die of starvation and others migrate to Chile. " Red water " is also frequently reported as a consequence of " El Niño." This may cause an acrid stench (cf., BRONGERSMA-SANDERS, 1948; WOODCOCK, 1948). Fish and large invertebrates subsequently die or are found in a moribund condition on the beaches. These " crash " periods have come to be expected at intervals of seven years (i.e., 1911, 1918, 1925, 1932, 1939 and 1941): some (1891, 1925, 1953) have been more severe than others. Various phases of these catastrophies have been described,[5] but there are few published data, other than surface temperatures. In many instances, these do not sufficiently identify the source of a given water mass.

During studies of the guano-producing birds in Peru (VOGT, 1942), it was evident that the birds' lives were so dependent on sea conditions, especially on the abundance of anchovies, that a preliminary oceanographic and biological survey of Pisco Bay was made during the latter part of 1941. Surface and subsurface temperatures were observed at weekly intervals over an area of roughly 400 square miles (Fig. 1). Water samples for salinity determinations[6] were obtained, if possible, when occupying a station for the first time. These were the first subsurface observations in the littoral zone off the coast of Peru to be taken at close intervals in time and space and also under more or less " normal " conditions.

On two occasions, temperature and salinity data, as well as plankton samples were collected to the north and offshore west of Chincha Norte for a distance of about 125 miles for comparison with earlier observations (Footnote 3). Temperatures were also recorded and phytoplankton samples gathered each morning in the immediate vicinity of Chincha Norte. In addition, anchovies were brought out to the island several days each week by local fishermen.

The survey in Pisco Bay was supplemented by a similar one in the waters off Cabo Blanco in January 1942.

STATEMENT OF THE PROBLEM

Anchovies are the chief food of the guano-producing birds and disappearance of the fish means starvation for the birds (VOGT, 1942). Consequently, it is important to learn the circumstances under which the fish vanish from the surface of the Peruvian coastal waters. Two hypotheses as to where the fish disappear during the " crash " years have been proposed and both assume that high temperatures are directly responsible. One is that the anchovies migrate southward (VOGT, 1942) and this is in keeping with the idea that the " crash " years result from an unusual invasion of warm water (" El Niño ") from the north. The other (DEL SOLAR, 1942) suggests that the schools of anchovies move offshore into cool deep water. This suggestion is based on the fact that the tunas which invade the coastal areas at such times have preyed upon anchovies. There is little or no precise evidence to prove the validity of either proposal.

Some (SCHWEIGGER, 1943, p. 37) believe that the Peruvian anchovy feeds primarily on copepods and that they therefore follow the latter[7] into deeper water during

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[5] CURRIE, 1953a; JAMES, 1953; RAHM, 1937; SHEPPARD, 1931; STIGLICH, 1925; WILSON-BARKER, 1931, in addition to those cited in the text above.

[6] Salinity titrations were carried out by members of the technical staff at the Woods Hole Oceanographic Institution. Because the method is not reliable, the salinities determined by hydrometer readings are not included in the discussion.

[7] CLARKE, 1933, 1934, 1934a; GARDINER, 1933; HANSEN, 1951; JOHNSON, 1942; NICHOLLS, 1934; ROSE, 1925; RUSSELL, 1925, 1926, 1927, 1927a, 1928, 1928a.

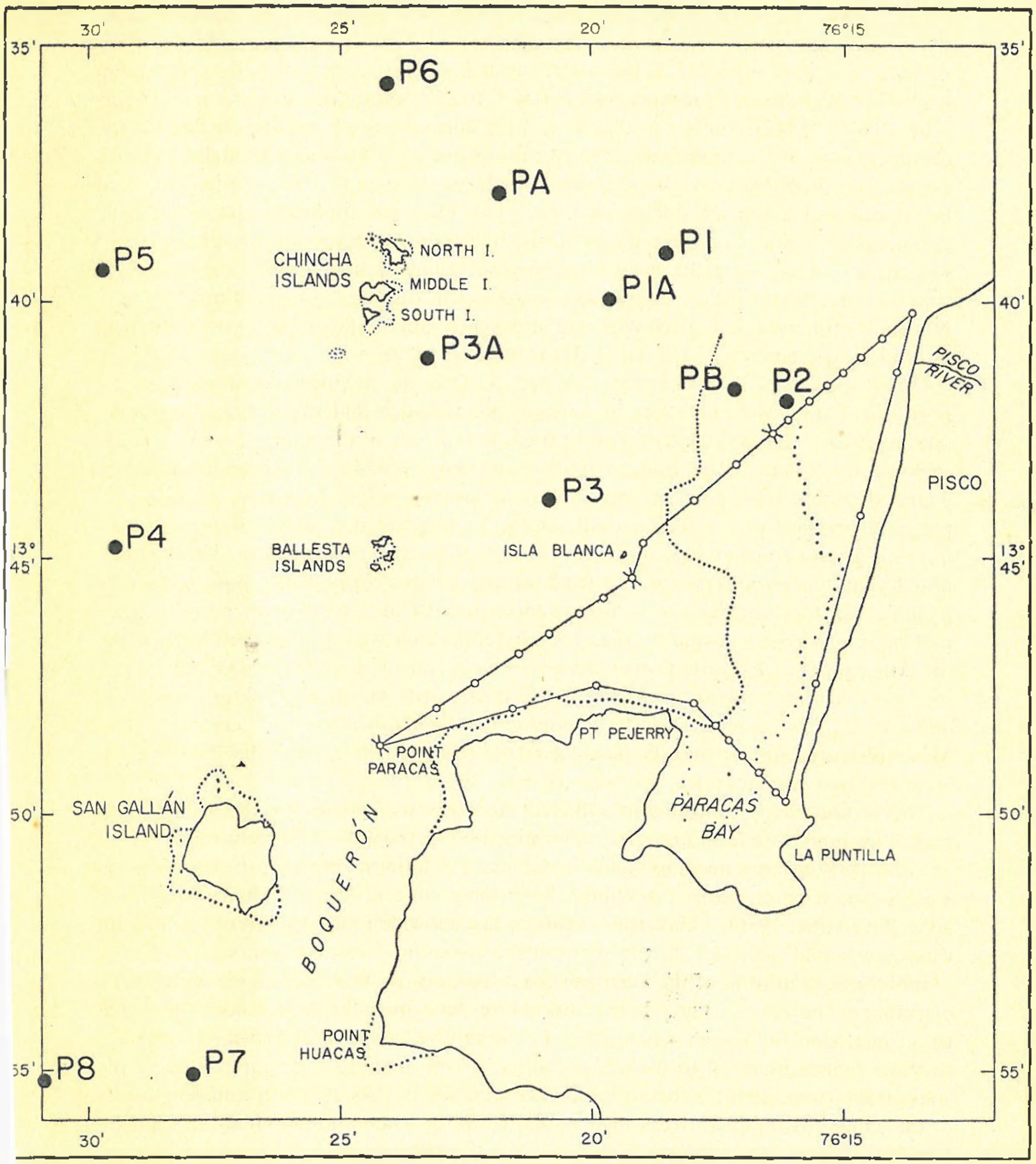

Fig. 1. Place-name chart of Pisco Bay and vicinity showing position of stations listed in Table 2, Section A. The positions of the stations in Fig. 4 are also plotted and those with the symbol ✱ indicate stations where subsurface temperatures were taken at 10 and 20 metres.

the day. There are a few observations which seem to indicate that such a diurnal migration of anchovies may take place when the water is warmer than 20°C (HUTCHINSON, 1950). However, other than these records such evidence as we have indicates that this is not usually the case. During the " El Niño " period of 1953, schools of anchovies were reported at the surface in the general vicinity of Lobos de Afuera in northern Peru in water temperatures of 24°C to 25°C (SCHWEIGGER, 1953). Furthermore, VOGT, (1942) points out that were such diurnal migrations responsible for the disappearance of the anchovies, they would return to the surface at night. In this event, it is probable that the pelicans, which are known to feed at night, if need be, would prey upon the anchovies then. This does not apparently happen during catastrophic periods, because the pelicans, like the cormorants and boobies, die of starvation. Also, were the anchovies preying primarily upon copepods one might suppose that this sort of migration would occur during " good " times as well. Normally, however, the anchovies are sufficiently abundant at the surface to meet the food requirements of the birds (HUTCHINSON, 1950).

Other species of anchovy are reported to feed on phytoplankton at least for portions of the year[8] and there is considerable evidence that the Peruvian anchovy does likewise. The presence of diatom frustules of some of the more resistant species, such as are found in the bottom mud (NEAVERSON, 1934), have been recorded in guano deposits, both ancient and modern (CANCINO, 1950; MURPHY, 1936, p. 97; personal observations). This would appear to indicate that diatoms were present in the digestive tract of fish which the birds had eaten. Furthermore, VOGT (1942) noted that the periods when the food supply of the cormorants appeared to be plentiful, as reported by the wardens, corresponded in general with periods when the water was least transparent (i.e., the phytoplankton was so abundant as to make the water murky). Examination of the stomach contents of more than 2,000 individuals indicate that the Peruvian anchovy does feed primarily on phytoplankton, especially diatoms, at least over a period of months (29 September to 19 December 1941). More recently, similar results have been obtained which extend the period from June through January and February (ROJAS, 1953).

The production of diatoms in sufficient numbers to provide for the guano birds and other predators is in large part determined by the supply of nutrient salts. These are not likely to be a limiting factor under usual conditions because the cool coastal waters which result from upwelling[9] keep their concentration high in the photic zone (GUNTHER, 1936). Therefore events in the sea which might interrupt or disrupt this cycle could account for the recurrent disasters in " crash " years.

Biological calamities of the Peruvian coast have always been associated with undue warming of the water. These high temperatures have most frequently been arttibuted to an incursion of fresher water from the north (" El Niño "). At times, however, they have been ascribed to wedges of saltier, warm offshore water approaching the coast (GUNTHER, 1936; SCHWEIGGER, 1942, pp. 71-73; VOGT, 1942) and sometimes to the effluent from local rivers such as that from the Pisco and San Juan de Chincha Rivers (SCHWEIGGER, 1942, pp. 77-80). It has also been suggested that solar radiation

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[8] There are a number of papers (ANDREU y RODRÍGUEZ-RODA, 1951; DEBUEN, 1931; FAGE, 1911, 1920; MIRANDA y RIVERA, 1930) which provide background information on feeding, migrations, etc., for the Mediterranean anchovy.

[9] GUNTHER, 1936; SCHOTT, 1931, 1932; SVERDRUP, 1930, 1931. Also, cf., CURRIE, 1953, for the Benguela Current and SVERDRUP and FLEMING, 1941, and California, Marine Research Committee, 1953, for the California coast.

may be significant in local warming (Schweigger, 1942, p. 77). Whether the effect of high temperatures be a direct one or an indirect one due to differences in the concentration of nutrient salts of the water masses concerned, the reasons for such temperature increases are important in understanding the ecological relationships of the Peruvian coastal waters. Consequently, an attempt is made here to distinguish the relative importance of the several types of warming.

WARMING IN PISCO BAY

Warm temperatures due to an incursion of " El Niño " are said to extend at times as far south as Pisco Bay. In 1925, there were a sufficient number of surface temperatures recorded from vessels traversing the waters of the Peruvian coast to document a progressive southward advance of temperature increases as far south as Pisco Bay (Schott, 1931, pp. 211-212; Murphy, 1926; Zorell, 1928). These persisted in Pisco Bay from 15 to 24 March. Subsequently, it has been learned that surface temperatures as high as 20°C to 22°C are common in the Bay and even as high as 24°C to 25°C are not infrequent in February, March and possibly even in April. These temperatures are not considered to have resulted from an incursion of " El Niño " (Schweigger, 1942; Vogt, 1942). More recently (1953), when " El Niño " extended only as far south as Paita, warming *in situ* took place to the south apparently due to a cessation of upwelling (Avila, 1953). Since this was the worst " El Niño " year since 1925, the possibility is raised that a similar situation existed in 1925 and that " El Niño " was not responsible for the temperature increase in Pisco Bay that year.

To verify the characteristics of " El Niño " water, simultaneous observations of temperature and salinity at several subsurface depths were made off Cabo Blanco (4°16′ S, 81°15′ W) in January 1942, the season when " El Niño " might be expected there. The resulting T-S diagram (Fig. 2) indicates that in the upper 25 metres, the temperatures were as high (21°C to 23°C) or a little higher than off Pisco, but the salinities were consistently lower than might be expected for these temperatures in the Pisco Bay area (Fig. 2; cf., Tables 1 and 2). The layer of fresher water was 3 to 10 metres deep within about 1·5 miles from the beach and 25 metres deep at about 30 miles offshore. Below 50 metres, the water had essentially the same characteristics as in the vicinity of Pisco Bay. At intermediate depths, the water appeared to be a mixture of the two.

Fresher water similar to that found off Cabo Blanco in January 1942 (Fig. 2) was found extending northward from Lobitos in September 1927 and November 1929 (Deutschen Seewarte, 1930), to the north and west in July and August 1931 (Discovery Committee, 1949, Sta. Nos. 708-712, 715-719), and also as far south as 8°51′ S, 79°31′ W in March 1931 (Schott, 1931, p. 245). The latter, it should be noted, was farther south than in 1953 and yet there is no mention in the scientific literature, insofar as I am aware, to indicate that 1931 was a " crash " year. Water of this sort was not found in the Pisco area during the latter part of 1941 or in 1953 (Avila, 1953; Posner, 1953).[10] Thus, at times, situations off the Peruvian coast, formerly attributed to " El Niño " are not of this origin as already recognised by Gunther (1936), Schweigger (1942), and Vogt (1942).

[10] Schweigger (1953) has entered some salinity data on charts, but without giving the temperatures taken at the same time. Insofar as one can judge by interpolation of the temperatures, the salinity values given on Map Nos. 3, 4 and 5 appear to be in agreement with other reports. Those on Map Nos. 1 and 2 appear to indicate that " El Niño " water was present.

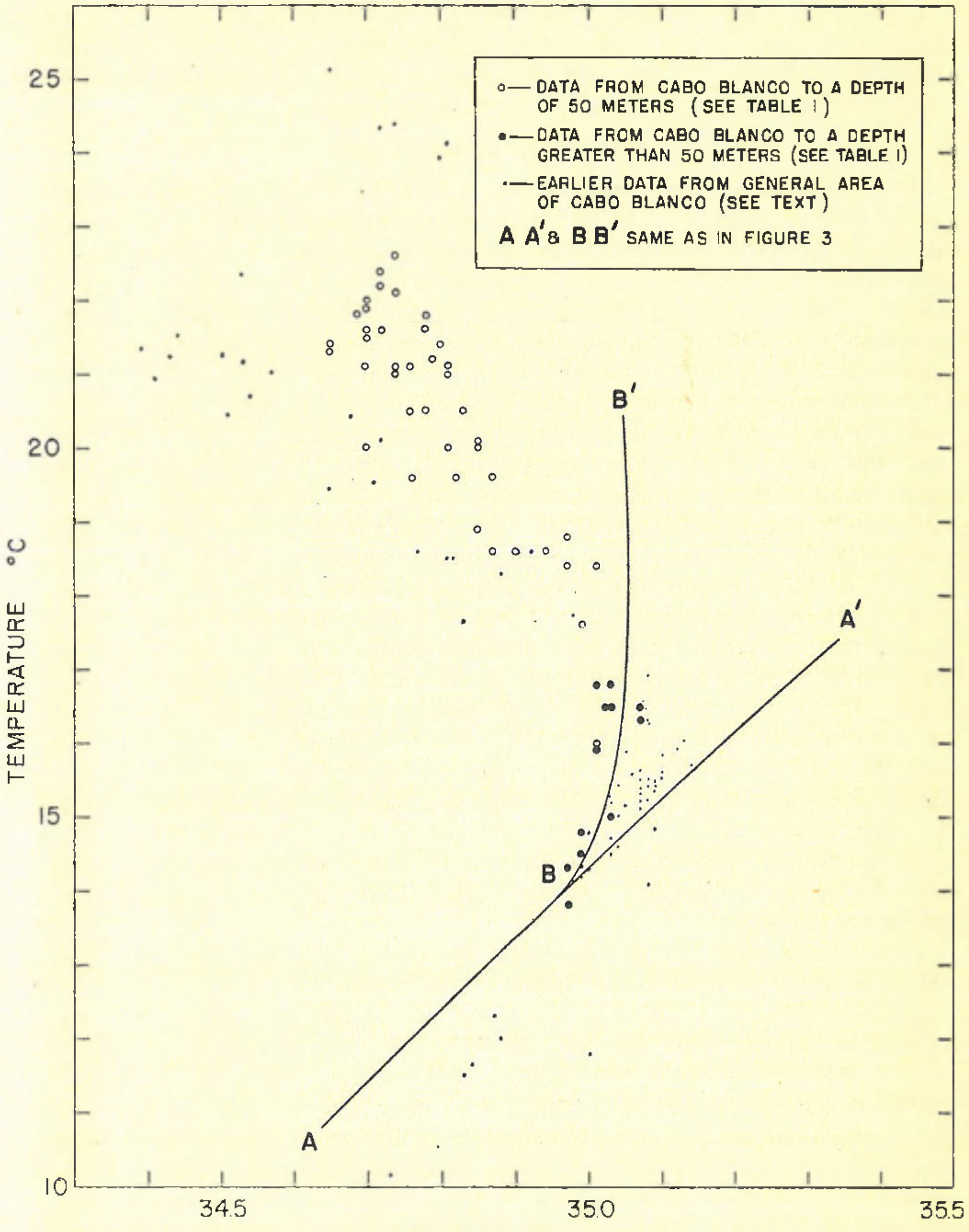

Fig. 2. T-S diagram comparing characteristics of the water in the Cabo Blanco area with earlier records of similar origin.

Intrusions of tongues of warm offshore water, first mentioned by GUNTHER (1936) have been considered as a source of higher temperatures in Pisco Bay (GUNTHER, 1936, p. 194; SCHWEIGGER, 1942, pp. 71-73; VOGT, 1942) but these observations were not accompanied by salinity determinations to prove their offshore origin. To ascertain whether offshore water has been found in the general vicinity of Pisco Bay, the available temperature and salinity data from pertinent depths out to 85° W, and from 5°S to 17°S were plotted on a conventional T-S diagram[11] for comparison with those from the *Carnegie* in the same latitudes, between 90°W and 115°W (*Carnegie* Sta. Nos. 46, 47, 75, 76, 77, 78, 79). The latter are situated where a maximum salinity obtains (Fig. 3, AA′) and may be considered as characteristic of the water masses from the Eastern South Pacific as a whole.[12] The great majority of the points fall within relatively narrow limits for depths greater than 200 metres (Fig. 3), but at lesser depths there is a marked scattering at most stations between the Peruvian coast and 95°W. The scatter is accentuated when curves are plotted for individual stations. These curves, because of the uniformity in salinity in the upper layers, are indicative of upwelling (as will be mentioned again in another connection). Both presentations indicate that the water is distinctly fresher and usually somewhat cooler in the shallower layers than is characteristic for the Eastern South Pacific as a whole (Fig. 3, AA′). These data suggest, then, that the relatively warm saline water characteristic of the Eastern South Pacific does not ordinarily occur within several hundred miles of the South American coast. The *William Scoresby* observations for depths down to between 30 and 50 metres at Sta. Nos. 667, 668, 670, 671, 674, 682, 683, 686, 730, 731 and 734, as well as those taken from the *Oldenberg* (DEUTSCHEN SEEWARTE, 1930) at the surface west of 80°W in the sector under consideration are the exceptions. The data from the shallow depths at these stations fall close to AA′ on the T-S diagram (Fig. 3), indicating an offshore origin. Only three, however, are on the continental shelf and none are within about twenty miles of shore. Although such water was found about 112 miles to the westward at the time of our observations, it was not found in the Pisco Bay area. It therefore remains to be learned whether warm offshore water with salinities higher than about 35·3‰ ever significantly affects the Pisco area.[13]

Within Pisco Bay proper (Fig. 3), all temperatures and salinity data when plotted on a T-S diagram (Table 2; FUNDER, 1916) fall along BB′, almost at right angles to the abscissa. The salinity does not vary by more than about 0·15‰ between the greatest subsurface depth on the continental shelf and the surface even although the temperatures vary from 13·8°C to 20·0°C, the extremes found in the area at the time of our observations. Water of 13°C to 14°C, the minimal recorded in the Bay, is usually found with salinities of 34·96‰ to 35·06‰ at depths of 150 to 200 metres, perhaps a little deeper (250-300 metres) at stations off the continental shelf

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[11] Such a wide latitudinal span was included because so few observations have been made within the immediate offing of Pisco Bay. Since the scatter at shallower depths was as marked when only the few data between 12°S and 14°S were used, it does not appear that for purposes of the present analysis any undue inconsistencies were introduced.

[12] There seems to be some precedent for such a procedure (REDFIELD, 1950; SVERDRUP, JOHNSON and FLEMING, 1942, Fig. 194; FLEMING, *et al.*, 1945, Figs. 205, Sta. Nos. 78-89; SVERDRUP, *et al.*, 1944, pp. 126-127, Fig. 14).

[13] SCHWEIGGER (1947, p. 60) reports salinities of 35·25‰ but corresponding temperatures and localities are not given. Although this value is relatively high for recently upwelled water, it has been recorded at temperatures between 13° and 14°C. It therefore is not possible to determine the source of a water mass with such salinity values without more data.

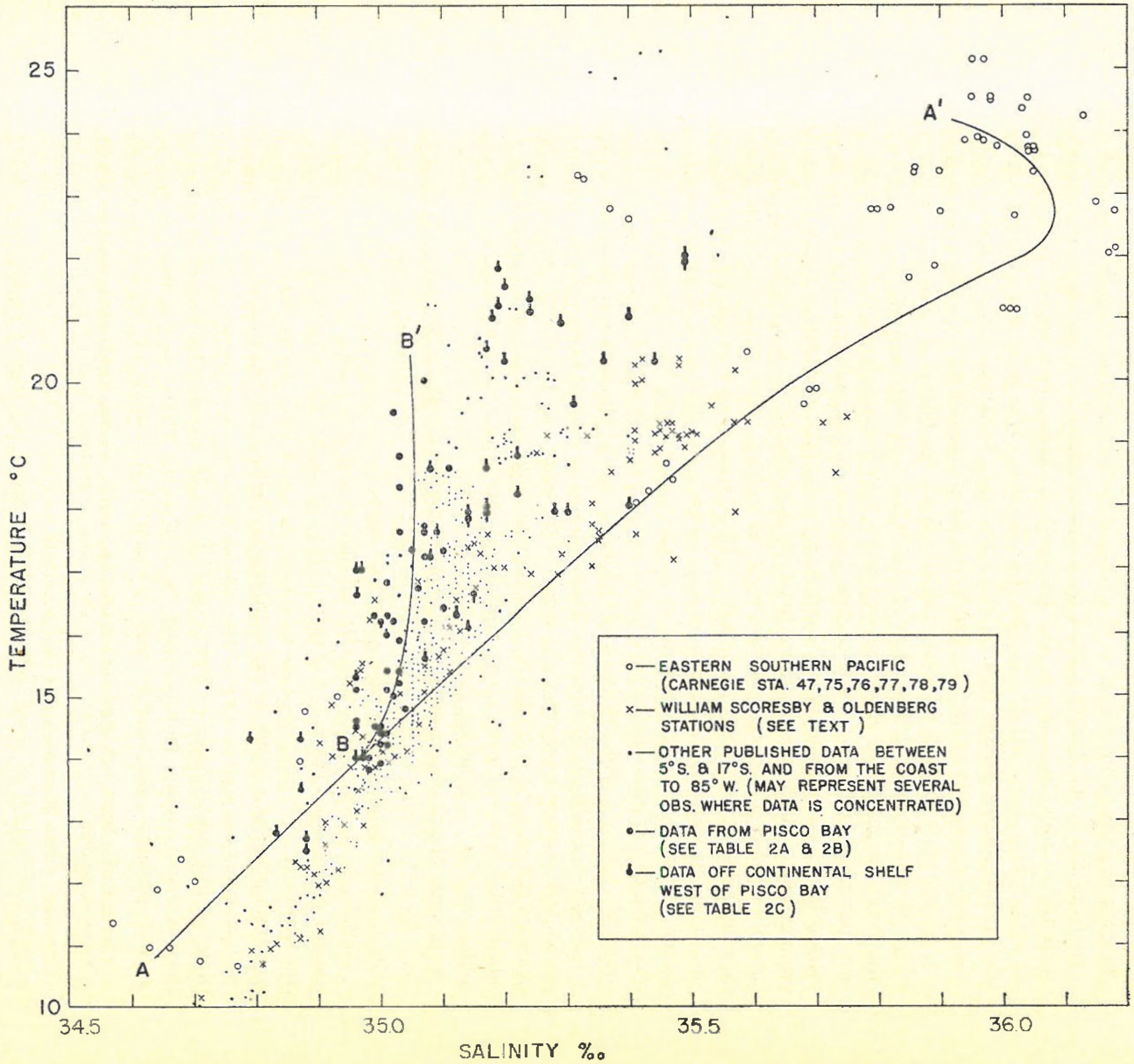


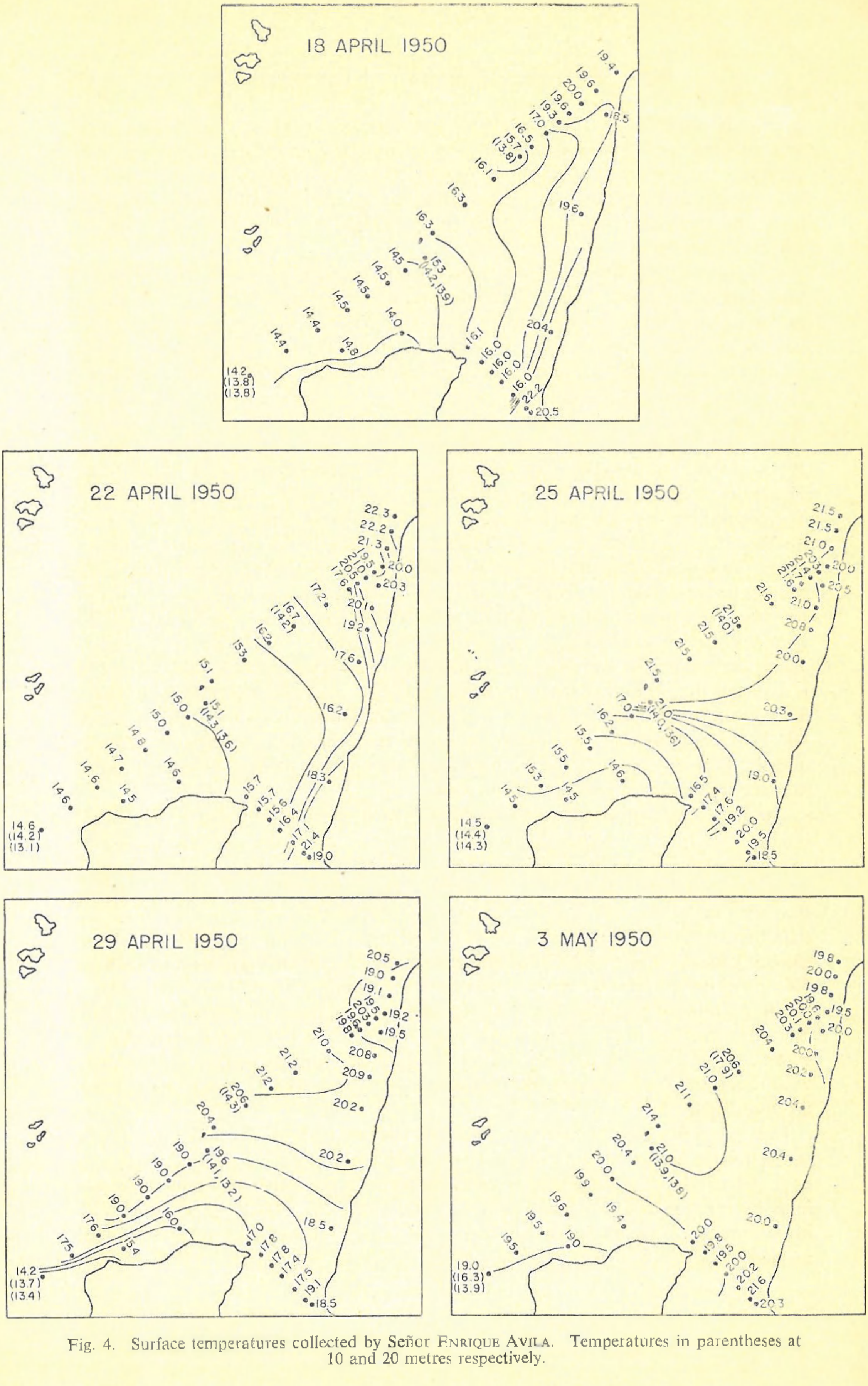
Fig. 3. T-S diagram comparing characteristics of inshore water with that of the Eastern South Pacific as a whole.

as already reported by Gunther (1936) and Sverdrup (1930). Our stations to the west of Chincha Norte indicate that even within 100 miles of the island these temperatures may be found at depths of 100 to 200 metres. In short, the uniformity of the salinities in Pisco Bay may be accounted for by upwelling from some subsurface layer and the higher temperatures in all probability by solar warming *in situ*, as will be shown below.

It is possible to estimate roughly whether solar warming in the absence of marked upwelling could produce the higher temperatures recorded in 1941. In these computations, it is necessary to simplify the conditions which probably existed in the bay by neglecting currents and horizontal mixing. On the other hand, a certain amount of downward mixing must be assumed to account for observed temperatures at a station close to Chincha Norte where weekly temperatures at 10-metre intervals down to 50 metres were recorded for the latter part of 1940 and much of 1941 (Table 3). Averages for this water column reveal a noticeable warming as early as 29 December 1940 (Table 3), a warming which continued until mid-March 1941. Thereafter, it cooled gradually until mid-June, when the observations were suspended. The greatest increase between any two sets of observations in the average temperature for the 50-metre column was 2·1°C (Table 3) between 19 January and 16 February 1941. To raise the temperature of this column of water by 2°C requires 10,000 gram calories per square centimetre of sea surface or 358 gram calories per square centimetre per day. For the season and latitude under consideration, it is estimated that the average radiation from sun and sky amounts to at least 432 to 648 gram calories per square centimetre per day (Sverdrup, Johnson and Fleming, 1942, Table 25). If it is assumed that reflection from the water surface is negligible (Sverdrup, Johnson and Fleming, 1942, Table 26) and that all the radiation enters the water it would take between fifteen and twenty-three days to produce the observed warming. Consequently, only 55% to 82% of the heat available appears to have been required to produce the observed temperature increase.

The most extreme temperatures recorded within the Bay can also be accounted for in this way. The higher temperatures appear to emanante from the inner part of the Bay off Pisco (Fig. 4; Schweigger, 1942) in an area (Fig. 1) which roughly coincides with depths of less than 20 metres. The same number of calories entering through the surface will increase the average temperature of shallow waters more than that of deep. Thus, during the period required to warm the 50-metre column close to Chincha Norte by 2°C, the temperature off Pisco would have risen by perhaps 5°C and in Paracas Bay by 10°C. This means if we assume that the water throughout the Bay averaged roughly 17·4°C at the start and warmed to 19·4°C at Chincha Norte the temperature off Pisco might have risen to 22·4°C and in Paracas Bay to 27·4°C during the same period. Except for the latter, similar surface temperatures have frequently been reported (Schweigger, 1942; Vogt, 1942; Avila, 1949, 1950. See also Table 2).

Thus far, it has been assumed that a certain amount of heat was mixed downward through wave action or some such turbulent process, but during periods of calm, a large percentage of the warming would take place in the upper metre of the water mass (Sverdrup, Johnson and Fleming, 1942, Table 28). Under these conditions in midsummer (January-February), one could expect for each day of calm to find an increase of 2·38°C to 5·35°C at the surface. Increases of 1·8°C to 2·4°C (Schweig-


18 APRIL 1950

22 APRIL 1950

25 APRIL 1950

29 APRIL 1950

3 MAY 1950

Fig. 4. Surface temperatures collected by Señor Enrique Avila. Temperatures in parentheses at 10 and 20 metres respectively.

ger, 1942, Map 22; Avila, 1950) have actually been reported between 6 a.m. and about 2 p.m. and of 4·5°C in a twenty-four hour period at Chincha Norte (Vogt, unpublished data, January 1940).

In addition to these isolated examples, the surveys made of the inner portion of the Bay in April 1950 (Avila, 1950) illustrate the same sort of warming over a considerable area (Fig. 4). It may be assumed that the water in the Bay had upwelled very shortly before his surveys started, because the temperatures were 14·2°C at 10 metres and 13·9°C at 20 metres. Only the shallowest layers in the inner part of the Bay showed any significant warming (Fig. 4). With an estimated 410 to 432 gram calories per square centimetre per day in this latitude in April (Sverdrup, Johnson and Fleming, 1942, Table 25) there was enough heat to warm a layer about 10 metres deep by 1°C in about two and a half days. An increase of 1°C was actually observed off Pisco between 18 and 22 April 1950 (Fig. 4). Similarly, it might be expected that the observed increase of 4·8°C between 22 and 25 April was restricted to a shallower depth indicating that there had been little mixing. The slight decrease at the surface between 29 April and 3 May does not necessarily indicate an intrusion of cold water, but rather a mixing down to at least 10 metres (Fig. 4), since the average temperature had increased to that depth by 1·5°C (cf., Freeman, 1953). At the northerly entrance to the Boquerón, however, the increase in temperature is nearly twice as great (i.e., 3·5°C) as could be accounted for by solar radiation alone. In situations such as this, one can only assume in the absence of any precise information that local water movements may in some way account for the increase. In any event, the area with water as warm as 15°C to 21°C or more was progressively expanding and moving toward the Boquerón between 18 April and 3 May (Fig. 4).

It also appears more reasonable to explain the existence of warm water in the inner part of the Bay as resulting from water warming over shallow bottom rather than from the river outflows. Recent studies[14] of rivers with a discharge several hundred times greater than those entering Pisco Bay have provided a convenient method for computing the effect of river effluent on adjacent bodies of water. It is obvious from these that the relatively small streams entering Pisco Bay could only have an infinitesimal effect on the salinity of the area.[15] The same conclusion could

[14] Ford, 1949; Ketchum, 1950, 1951, 1951a; Ketchum, Redfield and Ayers, 1950.

[15] The fraction of fresh water (F) in any sample required to reduce the salinity observed at the time of my survey (i.e., about 35‰ by merely one part per thousand over the surface of the Pisco Bay area is found by the following relationships (Ketchum, Redfield and Ayers, 1950, p. 28):

$$F = \frac{35 - 34}{35} = \frac{1}{35} = 0{\cdot}0286.$$

The general area under consideration is roughly 400 square miles or about 14·8 × 10^9 square feet. For convenience in computation, we may take into consideration only the surface layer to a depth of one foot. The volume of fresh water required to decrease the salinity by only one part per thousand is found by multiplying the fraction (F) by the volume of water in the surface layer to a depth of one foot :

$$0{\cdot}0286 \times 14{\cdot}8 \times 10^9 \text{ cubic feet}$$
$$= 423 \times 10^6 \text{ cubic feet}$$

The flow from both rivers entering the area is reported to be roughly 76,000 litres per day (Schweigger, 1942, p. 80). Therefore before enough fresh water could enter from this source to effect a change of one part per thousand in the salinity, it would take: $\frac{423 \times 10^6}{2{\cdot}63 \times 10^3} = 160{,}000$ days or more than 400 years, provided that all other processes which might tend to increase or decrease the salinity be inactive.

be reached by considering the heat contribution of the rivers. We can, therefore, dismiss the discharge from the two rivers as a means of increasing the surface temperature of Pisco Bay in any significant way, especially since the salinity normally tends to increase, not decrease, with temperature (Fig. 3).

Solar warming then can account for most of the sudden increases in temperature which have been observed in Pisco Bay from place to place and almost from hour to hour.

COOLING IN PISCO BAY

The cool water on the Peruvian coast upwells from subsurface layers with a temperature between 13°C and 14°C. (GUNTHER, 1936; SVERDRUP, 1930). Indications are that this water rises to the surface in the general vicinity of Punta Huacas south of the Boquerón (Fig. 1). The coldest water is frequently found there and extending northward into the Bay toward the Ballestas and Isla Blanca (Fig. 4). Not infrequently, surface temperatures below 15°C are found in this general vicinity (AVILA, 1949; 1950; MURPHY, 1923; SCHWEIGGER, 1942) and water of 13°C has actually been observed at the surface close to Isla Blanca. In 1941, the coldest water was somewhat warmer (between 14°C and 15°C), but nevertheless it too was found south of San Gallán at depths of 10 metres or more. Elsewhere it occurred as deep as 50 metres. In other years, as exemplified by 1950 (Fig. 4), temperatures of 14·0°C and 14·5°C occur over much of the southwestern portion of the Bay and its approaches and within 10 metres of the surface elsewhere.

As mentioned earlier, temperatures recorded in Paracas Bay are not as high as might be expected in an isolated shallow bay. The temperatures there the latter part of April 1940 (Fig. 4) indicate that the water east of Punta Pejerry was no warmer than much of Pisco Bay. On the other hand, close to La Puntilla, the morning temperatures was consistently cooler than one taken at the end of the circuit in early afternoon. It looks then as if cool water from the Boquerón flows north of the Paracas Peninsula and around Punta Pejerry into Paracas Bay. It may be that this is part of a counter clockwise circulation in the Bay, which would tend to develop as a result of the prevailing southeasterly wind.

This sort of temperature distribution means that with each pulse of upwelling, cold water surges into the Bay through the Boquerón. It is not possible to determine with existing data whether each such pulse flushes out the bay or whether the amount of water entering the Bay varies depending upon the strength of the upwelling. The cold temperatures so close to the surface in April 1950, together with the fact that most of the somewhat warmer surface temperatures observed in the Bay at that time can be accounted for by warming *in situ* of relatively short duration certainly seems to suggest that flushing may at times be practically complete.

In the computations of warming from solar radiation, mixing was considered as a mechanism for distributing heat downward from the surface. However, the Bay is not an isolated body of water as this might imply. Under somewhat different circumstances, mixing can also be a means of cooling (cf., FREEMAN, 1953). The warm temperatures observed at the surface with a sufficiently strong wind would mix with the cold water existing below 10 metres with the result that the surface temperature would be considerably reduced. Under such circumstances, surface cooling is not indicative of a new intrusion of cold water. Once again, it appears that surface temperatures are not reliable when interpreting hydrographic conditions.

TEMPERATURES IN "CRASH" AND "NORMAL" YEARS

Surface temperatures of 20°C to 21°C or even higher occur over large portions of the Bay much of the year, in both "crash" years and "normal" ones. They are therefore not a reliable index for differentiating between them. On the other hand, subsurface temperatures may prove useful in this respect. In a "crash" year, such as 1941, the warming process is predominant, apparently through a cessation of upwelling for a more or less prolonged period. In the absence of upwelling, the water in the Bay is warmed by the sun. Through mixing the warming extends downward depressing the isotherm for 14°C to a depth of 50 metres or more and it may then remain deep for as long as six months from midsummer to midwinter (Table 3). Even in the absence of upwelling, some seasonal cooling takes place in late spring before the heavy cloud develops, a cloud which hangs over the coastal region perhaps eighty per cent of the time during the winter months (U.S. Navy Hydrographic Office, 1938). Despite this cooling, the isotherm for 14°C tends to remain deep, until upwelling again becomes active.

In a "normal" year, such as 1950, the cooling process appears to dominate except at the very surface, presumably because of repeated upwelling, possibly as often as every two or three weeks. Were upwelling more infrequent, it might be expected that the water column down to at least 50 metres would warm by about 2°C, as it did in 1941. Judging from the situation in April 1950 (Fig. 4), this does not happen, but rather the 14°C-isotherm lies within 10 to 20 metres of the surface and the temperature for the water column down to 50 metres averages close to 14·5°C rather than 18°C as in 1941. Superficial temperatures may, however, be as high as in a "crash" year following several days of calm or light winds.

ANNUAL TEMPERATURE CYCLE

One further point needs to be considered in trying to understand the hydrographic situation in Pisco Bay, namely, the annual temperature cycle. In most earlier discussions, this has not been stressed, perhaps because the significant temperature changes have always been so sudden and catastrophic. Nevertheless, such a cycle appears to exist in the surface layers, at least, for certain sectors of the coast (SCHWEIGGER, 1951; U.S. Coast and Geodetic Survey, 1948; U.S. Navy Hydrographic Office, 1938) with an average difference between summer and winter of roughly 7°C. Temperature differences of this magnitude in such low latitudes could readily be explained by the low dense cloud present nearly 80 per cent of the time during the months of July, August and September in contrast to practically clear skies from January through April (U.S. Navy Hydrographic Office, 1938). Such a cycle is revealed when surface data are averaged over a considerable number of years (SCHWEIGGER, 1951). From these, it appears that the extreme surface temperatures for any year along the Peruvian coast at least as far south as 12°S, whether in "normal" or "crash" years is usually as great as any ever recorded in Pisco Bay (SCHWEIGGER, 1951).

Some caution must be used, however, in interpreting averaged data of this sort, as the actual situation may be obscured. This has been demonstrated in studies of the Gulf Stream, for example (FUGLISTER, 1951). In a warm year, such as 1941, a year which was characterized by an almost complete absence of upwelling, the annual cycle was apparent in both surface and subsurface layers. In more usual years, such as 1950, it seems likely that the temperature cycle for the water column as a whole will be completely obscured by upwelling, which may also keep the surface temperatures low. It might also be expected that the surface temperatures might fluctuate markedly increasing during periods of calm or light winds, but decreasing with stronger winds.

COMPARISON WITH OTHER AREAS

Temperatures of the Peruvian littoral are not as extreme as those in some temperate regions, such as along the east coast of the United States. There, for example, at the warmest season, the surface temperatures from Chesapeake Bay to Cape Cod (Bigelow, 1933, Fig. 35) are the same or even a little higher (i.e., 23°C to 26°C) than in Pisco Bay. The winter temperatures, however, are very much lower, ranging from about 2°C to 8°C.

Likewise, in midsummer, when a marked thermocline is established, there may be a considerably greater contrast in the vertical temperature distribution off the east coast of the United States. There a pool of cool water of from 6°C to 8°C lies at depths of 40 metres or more (Bigelow, 1933, Figs. 41-44), but the surface temperature may be as high as 25°C. Within 25 metres there may thus be a vertical temperature gradient of 16°C, a range greater than any ever recorded on the Peruvian coast.

Similarly, the salinities regularly occurring along the Peruvian coast are much more uniform than along the east coast of the United States. Ordinarily, on the coast of Peru, salinities do not vary by as much as 1‰, never by more than 2‰. To be sure, at the mouth of a stream, this might not be true, but freshening from this source, as already pointed out, is insignificant for the Coastal Current as a whole. In contrast, off the east coast of the United States, crossing the continental shelf somewhat north of Cape Hatteras, the salinities may vary between 29·96‰ to 35·9‰, a gradient of 6‰. Vertically, in as little as 20 metres, the gradient may be 2·95‰ (29·96‰ at the surface and 32·91‰ at 20 metres) (Bigelow and Sears, 1935, Fig. 8) and at one locality there may be an increase from 29·65‰ to 32·24‰ in a fortnight (Bigelow and Sears, 1935, Fig. 25). These are extreme values, but nevertheless they may be expected with some regularity over considerable areas at certain times of year.

In other areas, such as the Bay of Fundy, the annual temperature range (8·6°C to 10°C) and the annual salinity range (0·7‰ to 1·4‰) (Bailey, MacGregor and Hachey, 1954) are roughly the same as off the Peruvian coast. In the Mediterranean, the annual temperature limits (i.e., about 13°C to about 26°C) (Rodríguez-Roda, 1953) are almost identical with the most extreme temperatures of the Peruvian Coastal Current. Thus, the temperatures and salinities of the Peruvian Coastal Current are not unique nor are they extreme, a situation that appears to have been overlooked.

BIOLOGICAL CONSIDERATIONS

There are two types of biological disasters, both associated with high water temperatures and formerly considered as a consequence of "El Niño." The first is the disappearance of the anchovies. This is the cause of death from starvation among the guano birds. Warming *per se* could be responsible for this type of disaster despite the relatively narrow temperature limits of the Peruvian Coastal Current. A considerable number of the diatom species occurring there are also found in more temperate regions. It may be that the lower temperatures of the Current are near the upper limits of their tolerance. On the other hand, it might be that the supply of nutrient salts becomes depleted in the absence of upwelling. Thus the production of diatoms would be restricted. In either event, the anchovies would go elsewhere in search of food. These points need clarification.

The second type of disaster is associated with the appearance of " red water " (" aguaje "). There are numerous examples elsewhere that this is usually accompanied by a mass mortality of fish and larger invertebrates.[16] " Aguaje " (" red water ") has most frequently been reported as resulting from an incursion of " El Niño " (LAVALLE y GARCIA, 1918; SHEPPARD, 1931). It has also occurred in water of offshore origin (GUNTHER 1936a, pp. 57-58) and in October 1941 it was found in upwelled water between Chincha Norte and Tambo de Mora.

To illustrate the complexity of the problem, the situation existing at the time of the "aguaje" of October 1941 is recorded here in some detail. Several million odd cormorants nesting in the Ballestas were going out each day in search of food and sufficient numbers of anchovies were available to prevent a mass starvation of the birds and at times even to attract whales. One Sunday, thirteen were spouting at one time within view of Chincha Norte and schools of anchovies were breaking the surface. During this period of plenty, there are notations in my records which suggest that all was not going well in the area. Thus, on 27 October, going north toward Tambo de Mora, a station was taken where the temperature at the time was not extraordinarily high (20·5°C at the surface, 16°C at 5 metres and 14·7°C at 43 metres). The zooplankton nets came up loaded with a yellow-brown slime from decaying phytoplankton. We have no information as to the organisms concerned, but it is possible that they may have been the naked flagellate (VOGT, 1942, Photo A, opposite p. 111) observed at Pisco in considerable numbers at about this time. Two days later (29 October), there were dead sea slugs on the beach at Chincha Norte and on 30 October, dead " lissas " were reported at La Puntilla. Meanwhile a visitor from Lima (1 November) reported a putrefactive stench, characteristic of an " aguaje " all the way down the coast from Callao (cf., BRONGERSMA-SANDERS, 1948; RAHM, 1927; WOODCOCK, 1948). Yet that same day the birds had fed in the Bay and over the weekend (3-4 November), Pisco Bay was teeming with life, the whales mentioned above, anchovies, Munida, gray gulls, etc., in addition to the usual guano birds.

In most cases, " red water " is chiefly due to a very dense concentration of dinoflagellates (BRONGERSMA-SANDERS, 1948), with the individuals in any one swarm usually belonging to but one species. From one half to one million cells per litre merely give the appearance of a dingy chocolate colour to the water, a colour often seen on the Peruvian coast. If the number doubles the water becomes distinctly red (ALLEN, 1942). Apparently, dinoflagellates bloom most frequently at times when the water temperature is relatively high. They occur in boreal waters after the flowering of diatoms (BIGELOW, 1927), when the water there is warmest. Just as is

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[16] BHIMACHAR and GEORGE, 1950; BRONGERSMA-SANDERS, 1948; CHEW, 1953; CONNELL and CROSS, 1950; COPENHAGEN, 1953; DAVIS, 1948; GUNTER, *et al.*, 1948; HAYES and AUSTIN, 1951; SOMMER and CLARKE, 1948.

the case for diatoms (**Bigelow, Lillick** and **Sears**, 1940, p. 169), no one factor appears to stimulate their increase. Recently, it has been suggested that small water masses of low salinity appear to be favourable for the growth of a " red tide " (**Slobodkin**, 1953). Certain species of dinoflagellates do actually show a maximal reproductive rate when salinities are low (**Braarud**, 1951; **Nordli**, 1953). In view of the extremely slight runoff from streams entering Pisco Bay, it seems unlikely that similar conditions favour the development of an " aguaje " on the Peruvian coast. Earlier, **Ketchum** and **Keen** (1948) found 2½ to 10 times the maximal total of phosphorus to be expected in the sea during a " red tide " off the west coast of Florida. Thus, they seem to exclude the possibility that the blooms necesarily depend on upwelled, nutrient rich water. In some cases, it is believed that dinoflagellates become concentrated by convection cells (**Bary**, 1953). In short, it is unlikely that optimal conditions are the same for all species which may cause " red water."

An intrusion of a foreign water mass such as " El Niño " or offshore water is not a prerequisite for either type of biological disaster. It is now established that the upwelled water of the Peruvian Current may also produce such a bloom when it has warmed in the surface layers to a temperature of 20°C as described earlier. It seems likely that little further headway can be made in determining limiting factors other than heat, until some record of the species concerned together with the environmental conditions is made.

DISCUSSION

The problem presented above is obviously not a simple one and is far from solved. Much headway could be made with more quantitative information of the upwelling process similar to that obtained recently along the Californian coast (California, Marine Research Committee, 1953). There, not only have many more centres of upwelling been discovered in the last five years than had been previously known, but also a method is in course of development for measuring the intensity of upwelling in different localities. These studies show that the intensity of upwelling fluctuates from year to year, just as appears to be true on the Peruvian coast. An attempt was made in the work along the California coast to correlate the intensity of upwelling with an increasing wind stress. Although weather cycles are recognized on the Peruvian coast (**Rudolph**, 1953; **Willett** and **Rubin**, 1953) sufficient data have not accumulated there to determine any relationship between upwelling and meteorological phenomena. Such data, together with model studies in the laboratory (**Von Arx**, 1952) should provide significant clues for an understanding of the ecology of the Peruvian Coastal Current.

Consideration must also be given in future to the cycle of nutrient salts. Throughout the present paper, it has been assumed that they are usually in excess and that their disappearance when upwelling ceases may indirectly account for the disappearance of the anchovies. The question is complicated by the fact that it is not known whether the excreta of the birds make any significant contribution to the abundance of nutrients in the water. In a very limited area within a bay on Long Island, New York, it is estimated that four million ducks produce 2·7 million pounds of nitrogen and 0·82 million pounds of phosphorus per year (Woods Hole Oceanographic Institution, 1952). The uric acid deposited in the water is quickly changed into soluble nitrogenous compounds by bacteria. At the height of the season, small green algae are extremely numerous rather than more characteristic diatoms and dinoflagellates, possibly due to the abnormal nitrogen-phosphorus ratio. This suggests that in the vicinity of a guano island, despite a substantial deposit of guano on the island itself, there may also be a significant contribution to the surface waters. This might account for the dense population of a large naked flagellate in the latter part of October, when several million cormorants were nesting in the Ballestas.

Clarification of these two questions together with work presently in progress on the life history of the anchovy will go a long way toward accounting for the fluctuations in the amount of guano deposited on the islands from year to year and to an understanding of the high productivity of an area of active upwelling.

SUMMARY

1. The ecological situation in the Peruvian Coastal Current is reviewed.

2. It is suggested that during catastrophic periods, warming *in situ* in the absence of active upwellings is perhaps more frequent than a phenomenal incursion of " El Niño " like that of 1925 or of warm offshore water. Contributions from rivers appear negligible for the area as a whole.

3. Some consideration is given to the cooling process and its possible effect on the annual temperature cycle.

4. The annual temperature range appears to be about 7°C. and the salinity range less than 2‰, compared with a temperature range of 20°C or more and a salinity range of perhaps 6‰ in temperate coastal waters.

5. There are two types of biological disasters, both usually associated with warm water and formerly attributed to " El Niño." One is the series of events initiated by disappearance of the anchovies, the other by the development of " red water." The latter has been found not only as a consequence of an incursion of " El Niño " and of warm offshore water, but also in upwelled water which has warmed in the surface layers.

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Finally, I have had the advice and criticism in the preparation of the present report of Dr. JOHN C. AYERS, Dr. BOSTWICK H. KETCHUM, Dr. FRANCIS A. RICHARDS and Mr. WILLIAM S. VON ARX.

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Table 2 (*continued*)

Sta. P 5. Roughly 5 miles west of Chincha Norte.

Date	*9 Sept.*		*24 Sept.*	*7 Oct.*	*25 Oct.*	*8 Nov.*	*28 Nov.*	*10 Dec.*
Total depth (m)	122		124	134	117	120	127	121
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	17·1	16·3	17·0	18·0	18·0	16·2
5	16·2	35·00	17·0	15·6	17·0	18·0	17·0	16·0
10	–	–	15·5	15·6	17·0	17·8	16·2	15·9
25	14·5	34·99	14·6	14·7	16·1	16·9	15·3	15·0
50	14·0	–	14·2	14·4	14·7	14·6	14·6	14·8
75	13·8	–	–	–	–	–	–	–
100	–	–	14·0	14·2	13·7	13·9	14·5	13·6
115	–	–	13·9	–	13·6	–	–	–
125	–	–	–	14·2	–	–	–	–

Sta. P 6. Roughly 3 miles north of Chincha Norte through 7 October, thereafter 5 miles north of Chincha Norte.

Date	9 *Sept.*		16 *Sept.*	24 *Sept.*	1 *Oct.*	7 *Oct.*	13 *Oct.*	25 *Oct.*	29 *Oct.*	8 *Nov.*	28 *Nov.*	10 *Dec.*
Total depth (m)	87		92	95	91	97	88	95	86	101	97	91
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	17·1	17·7	16·9	17·2	15·8	17·7	20·1	19·8	21·6	17·6
5	19·5	35·02	16·6	17·4	16·0	16·2	15·3	16·0	18·6	18·5	19·4	15·6
10	–	–	16·1	16·5	15·8	16·6	15·1	16·0	15·6	17·2	15·4	15·5
25	15·4	35·01	15·0	15·1	14·7	14·9	14·7	15·1	15·0	15·9	15·1	15·0
50	14·2	–	14·3	14·3	14·3	14·5	14·4	14·5	14·5	14·4	14·7	14·5
70	14·0	34·98	14·1	14·0	14·2	14·2	13·6	14·2	14·5	14·0	–	–
80	–	–	–	–	–	–	–	–	–	–	–	14·0
97	–	–	–	–	–	–	–	–	–	–	14·5	–

Sta. P 7. Roughly 3 miles south of San Gallán and about 3 miles west of Point Huacas.

Date	11 *Sept.*		9 *Oct.*	14 *Nov.*	2 *Dec.*
Total depth (m)	92		93	90	86
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	16·7	15·8	17·6
5	15·0	35·02	15·4	15·8	16·6
10	–	–	15·0	15·4	16·0
25	14·2	35·00	14·9	15·3	15·3
50	13·9	35·00	14·4	14·6	14·6
75	13·8	34·98	14·2	14·4	–
80	–	–	–	–	14·1
100	–	–	–	–	–
150	–	–	–	–	–
180	–	–	–	–	–
185	–	–	–	–	–

Sta. P 8. Roughly 5 miles west of P 7.

Date	11 *Sept.*		9 *Oct.*	14 *Nov.*	30 *Nov.*
Total depth (m)	174		193	190	188
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Temp. in °C.*	*Temp. in °C.*
0	–	–	17·9	16·6	17·9
5	16·3	34·99	15·9	16·4	17·7
10	–	35·04	15·3	16·0	17·1
25	14·4	–	15·0	15·6	16·6
50	14·8	–	14·2	14·4	14·5
75	–	–	13·9	14·0	–
80	–	–	–	–	–
100	14·4	–	–	–	14·0
150	14·2	–	–	–	–
180	–	–	–	–	13·0
185	–	–	–	13·6	–

Table 2 (continued)

	Sta. P 9. Roughly 10 mi. W. of Chincha Norte.	Sta. P 10. Roughly 10-12 mi. N. of P 5.			Sta. PA. Roughly 3 mi. from P 6 toward Pisco.	Sta. PB. Roughly 9 mi. toward Pisco from P 6.
Date	7 *Oct.*	25 *Oct.*	8 *Nov.*	28 *Nov.*	16 *Sept.*	16 *Sept.*
Total depth (*m*)	148	94	114	99	72	25
Depths in (*m*)	*Temp.* in °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*
0	16·1	17·1	19·3	19·9	17·6	17·6
5	16·2	16·8	17·7	18·4	17·0	17·2
10	15·7	16·4	17·4	15·5	16·5	17·2
20	–	–	–	–	–	16·0
25	15·0	15·7	16·0	14·9	15·1	–
50	14·7	14·5	14·5	14·7	14·4	–
65	–	–	–	–	14·2	–
75	–	–	–	–	–	–
90	–	14·3	–	14·5	–	–
100	14·2	–	14·0	–	–	–
140	14·0	–	–	–	–	–

B. Miscellaneous stations.

Locality	1 mi. W. Pt. Huacas	About 4 mi. E. of Sta. P6	About 3 mi. toward Chincha Norte from previous column	Chincha Norte Station	Line of stations La Puntilla-Chincha Norte	
					About 4 mi. from La Puntilla	About 8 mi. from La Puntilla
Date	9 *Oct.*	29 *Oct.*	29 *Oct.*	29 *Oct.*	30 *Oct.*	30 *Oct.*
Total depth (*m*)	49	57	79	—	20	39
Depths in (*m*)	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*
0	16·2	20·6	20·0	21·1	20·3	19·7
5	16·1	18·5	19·3	18·4	18·0	16·7
10	14·6	15·9	16·9	16·9	16·1	15·3
15	–	–	–	–	15·2	–
25	–	15·0	15·1	15·2	–	15·0
35	–	–	–	–	–	14·9
40	14·8	–	–	–	–	–
50	–	14·6	14·6	14·5	–	–
75	–	–	14·6	–	–	–

Table 2 (*continued*)

Locality	Line of stations La Puntilla-Chincha Norte		About 1 mi. W. Ballesta Is.	About 2 mi. W. Pt. Huacas	About 7 mi. W. Pt. Huacas	Chincha Norte Station	
	12 mi. from La Puntilla	16 mi. from La Puntilla					
Date	30 *Oct.*	30 *Oct.*	31 *Oct.*	31 *Oct.*	31 *Oct.*	6 *Nov.*	28 *Nov.*
Total depth (*m*)	68	65	75	83	202		
Depths in (*m*)	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*	*Temp. in* °*C.*
0	19·6	21·3	16·9	16·9	16·9	20·2	19·9
5	18·4	18·9	16·9	16·7	16·7	19·8	18·5
10	15·6	17·0	15·9	15·9	16·4	17·7	15·8
25	14·7	15·2	14·9	14·8	16·0	15·5	15·1
50	14·4	14·4	14·5	14·6	14·8	14·6	14·6
70	–	–	14·4	–	–	–	–
75	–	–	–	14·4	–	–	–
100	–	–	–	–	14·0	–	–
195	–	–	–	–	13·0	–	–

C. Stations taken from the "Pacific Queen"

Locality	P 11 about 9 mi. toward Tambo de Mora from Chincha Norte		P 12. About 13·5 mi. toward Tambo de Mora from Chincha Norte		P 13. About 4·5 mi. W. P 12	P 14. About 9 mi. W. P 12		P15. 13·5 mi. W. P 12
Date	27 *Oct.*		27 *Oct.*		27 *Oct.*	27 *Oct.*		27 *Oct.*
Total depth (*m*)	38		11		52	91		110
Depths in (*m*)	*Temp. in* °*C.*	*Sal. in* ‰	*Temp. in* °*C.*	*Sal. in* ‰	*Temp. in* °*C.*	*Temp. in* °*C.*	*Sal. in* ‰	*Temp. in* °*C.*
0	17·6	35·07	20·0	35·07	20·6	18·3	35·03	19·6
5	15·9	35·03	17·3	35·05	16·0	16·3	35·01	19·4
6	–	–	–	–	15·4	–	–	–
7	–	–	–	–	15·2	–	–	–
8	–	–	16·2	35·02	–	–	–	–
10	15·4	35·03	–	–	15·2	16·0	35·01	17·3
25	15·2	35·03	–	–	14·9	15·1	35·01	16·0
43	–	–	–	–	14·7	–	–	–
50	–	–	–	–	–	14·4	35·01	14·5
75	–	–	–	–	–	14·2	35·01	–
100	–	–	–	–	–	–	–	14·2

Table 2 (*continued*)

Locality	P 16. 18 mi. W. P 12		P 17. About 9 mi. W. of Chincha Norte		P 18. About 22·5 mi. W. Chincha Norte		P 19. About 36 mi. W. Chincha Norte	
Date	27 *Oct.*		28 *Oct.*		28 *Oct.*		28 *Oct.*	
Total depth (m)	120		129		255		over 200	
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*
0	18·8	35·03	17·7	35·07	18·0	35·17	18·6	35·17
5	18·3	35·03	17·3	35·10	17·9	35·30	17·9	35·14
10	17·6	35·03	17·2	35·07	17·9	35·17	17·9	35·14
25	16·4	35·10	16·2	35·07	17·9	35·28	17·8	35·14
50	15·1	34·96	14·5	34·96	16·3	35·12	16·1	35·14
100	14·2	35·01	14·0	34·96	14·0	34·97	–	35·16
200	–	–	–	–	12·7	34·88	12·5	34·88

Locality	P 20. About 13·5 mi. W. Chincha Norte	P 21. About 27 mi. W. Chincha Norte		P 22. About 40·5 mi. W. Chincha Norte		P 23. About 112·5 mi. W. Chincha Norte	
Date	15 *Dec.*	15 *Dec.*		15 *Dec.*		16 *Dec.*	
Total depth (m)	157	over 200		over 200		over 200	
Depths in (m)	*Temp. in °C.*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*
0	17·8	18·6	35·08	21·8	35·19	22·0	35·49
5	17·3	17·6	35·09	21·5	35·20	21·9	35·49
10	16·4	17·2	35·08	21·2	35·19	21·9	35·49
25	16·0	16·6	35·15	18·8	35·22	21·0	35·40
50	15·0	15·6	35·07	17·0	34·96	18·0	35·40
100	15·0	14·0	34·96	14·3	34·87	15·3	34·96
150	13·5	–	–	–	–	–	–
200	–	12·8	34·93	13·0	–	14·3	34·79

Locality	P 24. About 31 mi. E. P 23.		P 25. About 27 mi. E. P 24*	
Date	16 *Dec.*		16 *Dec.*	
Total depth (m)	over 200		over 200	
Depths in (m)	*Temp. in °C.*	*Sal. in ‰*	*Temp. in °C.*	*Sal. in ‰*
0	21·3	35·24	21·0	35·18
5	21·1	35·24	20·5	35·17
10	21·1	35·24	20·3	35·20
25	20·9	35·29	20·3	35·36
50	20·3	35·44	19·6	35·31
100	18·2	35·22	17·0	34·97
200	13·5	34·87	16·6	34·96

* The positions of the stations for 15 and 16 December are inaccurate. A course was set due West until reaching Sta. P 23 and then due East. At about midnight of 16 December, the " Pacific Queen " reached the light at Los Infiernillos about 1° of latitude south of Chincha Norte. This should not be interpreted as necessarily due to a current, since the ship's compass had not been adjusted recently.

Table 3. *Weekly temperature observations down to* 50 m. *in offing of Chincha Norte taken by Mr. William Vogt and Señor Enrique Avila*

Metres	1940 13 *Oct.*	20 *Oct.*	27 *Oct.*	10 *Nov.*	17 *Nov.*	1 *Dec.*	8 *Dec.*	15 *Dec.*	29 *Dec.*	1941 5 *Jan.*	12 *Jan.*	19 *Jan.*	16 *Feb.*
0	17·0	17·6	17·9	17·6	17·1	19·0	20·9	19·3	20·6	21·0	21·8	21·7	21·0
10	17·0	17·3	17·3	17·5	16·8	15·0	17·2	17·0	19·1	18·2	19·0	19·2	20·5
20	15·6	15·0	15·2	14·6	16·7	15·0	14·6	15·5	16·2	17·0	17·2	18·3	20·0
30	14·5	14·5	14·5	14·1	16·5	15·0	14·5	15·1	15·9	16·0	16·3	16·0	19·0
40	14·5	14·5	14·5	14·0	15·0	–	14·5	15·0	15·5	15·6	15·5	15·4	18·5
50	14·0	14·0	14·4	14·0	14·5	–	14·0	14·9	15·1	15·2	15·4	15·2	18·2
Average*	15·4	15·0	15·1	15·2	16·1	–	15·6	15·9	16·9	16·9	17·3	17·4	19 5

Metres	1941 23 *Feb.*	2 *Mar.*	9 *Mar.*	16 *Mar.*	30 *Mar.*	13 *Apr.*	20 *Apr.*	27 *Apr.*	4 *May*	11 *May*	18 *May*	8 *June*	16 *June*
0	22·0	24·0	24·0	23·3	22·0	19·5	18·7	18·6	19·6	19·9	20·0	19·0	18·4
10	21·0	23·2	23·0	22·2	21·3	19·4	18·6	18·4	19·4	19·2	19·0	18·9	17·0
20	19·6	20·1	20·6	21·8	21·2	19·0	18·0	18·0	18·9	18·3	18·0	18·8	16·2
30	19·5	19·9	19·9	21·2	20·9	18·8	17·4	17·8	18·2	17·8	17·2	18·6	15·7
40	19·2	19·1	19·7	20·9	20·3	18·2	17·2	17·6	17·5	17·2	17·0	18·0	15·0
50	19·0	18·9	19·5	20·3	20·2	18·0	17·0	17·0	17·0	17·0	16·1	17·0	14·9
Average	19·9	20·7	20·9	21·5	20·9	18·8	17·8	17·9	18·4	18·2	17·8	17·4	18·1

Metres	1941 7 *Sept.*	14 *Sept.*	21 *Sept.*	28 *Sept.*	12 *Oct.*	26 *Oct.*	2 *Nov.*	9 *Nov.*	23 *Nov.*	30 *Nov.*	7 *Dec.*	14 *Dec.*
0	16·0	17·4	17·4	16·8	15·5	18·5	19·0	17·7	19·6	18·5	16·5	19·0
10	14·5	17·1	17·2	15·9	15·4	18·3	18·0	17·6	16·4	15·6	16·3	17·5
20	14·0	15·0	16·7	14·9	15·2	15·2	16·0	15·8	15·0	15·3	15·7	15·7
30	14·0	14·6	15·3	14·5	15·0	15·1	15·6	15·4	14·7	15·0	15·0	14·7
40	13·9	14·0	14·8	14·4	15·0	14·7	14·8	15·0	14·5	14·7	14·9	14·6
50	13·9	13·9	14·6	14·4	15·0	14·4	14·7	14·7	14·4	14·6	14·8	14·6
Average	14·2	15·6	16·0	15·0	15·2	15·9	16·2	15·9	15·5	15·4	15·5	15·8

* The average for the column 50 metres deep was obtained by adding one-half the surface temperature, one-half the temperature at 50 metres and the temperatures at 10 m, 20 m, 30 m, and 40 m and dividing by 5.

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