THE OCEANOGRAPHY OF THE PERUVIAN LITTORAL WITH REFERENCE TO THE ABUNDANCE AND DISTRIBUTION OF MARINE LIFE

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The Humboldt Current, which flows northward along the Pacific coast of South America, is directly responsible for certain striking phenomena of oceanic distribution. It is responsible also for the existence in littoral waters of a vast abundance of marine organisms, upon which are dependent in turn unsurpassed fisheries resources, as well as the remarkable modern Peruvian guano industry concerning which authoritative information has recently become available.[1] Hydrographic and biological investigations in the Humboldt Current strike, therefore, at the roots of important problems of ecology, of the geographic distribution of life, and of the application of science to economic affairs. A discussion of these subjects in the light of information acquired during a recent expedition of the Brooklyn Museum[2] is the object of the present paper.

Characteristics of Oceanic Circulation Along the Coasts of America

For a comprehension of conditions in the Humboldt Current the circulation of both northern and southern hemispheres must be considered together; and, moreover, the system of the western coast of the Americas must be contrasted with the diametrically opposite expression of the same causes which obtains on the Atlantic side of the continents.

Owing to the progressive increase in the eastward linear velocity of the earth's surface from either pole toward the equator, masses (as of air or water) moving in the direction of the equator necessarily fail to maintain an easterly component equal to that of the parallels of latitude at which they are successively arriving. In other words, they "fall behind," or turn toward the right in the northern hemisphere and toward the left in the southern.[3]

[1] R. E. Coker: The Fisheries and the Guano Industry of Peru, *Bull. Bur. of Fisheries*, Vol. 28, 1908, Part I, pp. 333–365.

Idem: An Illustration of Practical Results from the Protection of Natural Resources, *Science*, No. 1370, Vol. 53, 1921, pp. 295–298.

J. A. de Lavalle: El guano y la agricultura nacional, Lima, [1914], p. 1–111.

R. C. Murphy: The Guano Industry of Modern Peru, *Brooklyn Museum Quart.*, Vol. 7, 1920, pp. 244–269.

[2] R. C. Murphy: The Seacoast and Islands of Peru, *Brooklyn Museum Quart.*, Vol. 7, No. 2, 1920, to Vol. 9, No. 4, 1922.

[3] For the mathematical explanation of this phenomenon see G. F. McEwen: Peculiarities of the California Climate Explained on the Basis of General Principles of Atmospheric and Oceanic Circulation, *Monthly Weather Rev.*, Vol. 42, 1914, pp. 14–23.

The converse is true of currents moving away from the equator or in the direction of the poles. These elementary facts explain why both the meteorological and the oceanic circulatory systems are clockwise in the northern hemisphere and counterclockwise in the southern hemisphere.

The primary geophysical results of the circumstances just cited are that in middle latitudes the movement of ocean currents along the east coast of both Americas is in the general direction of the poles, whereas on the west coast the flow is equatorward. It follows that in the Atlantic littoral region tropical or subtropical hydrographic conditions obtain through many degrees of latitude (roughly 60°), while in the Pacific littoral they are contracted to a breadth of barely 30° of latitude owing to the intrusion toward the equator of cool currents from both the north and the south. As a matter of fact, the only characteristically tropical or subtropical Pacific waters in contact with the coast of America lie in the narrow zone between the Gulf of Guayaquil (latitude 3° S.) and the Gulf of California.

The Humboldt Current

The Humboldt Current is a northerly branch of the Pacific Antarctic drift, and in both extent and influence it is perhaps the most remarkable of oceanic streams. It owes its origin chiefly to the prevailing westerly winds of high southern latitudes and to the meteorological whirl of the eastern South Pacific. It is particularly noteworthy for its sustained low temperature. The apparently anomalous circumstances were first noted by Alexander von Humboldt in 1802, when the great cosmographer observed surface temperatures of 59.9° F. at Callao in the early part of November—readings which were extraordinarily different from others taken in the outlying tropical Pacific. It has since been determined that the mean annual temperatures of waters close to the shore line of central Peru are, in fact, from 18° to 20° F. lower than the theoretical values for the latitudes.

The current laves the western coast of South America from a point somewhere south of 40° S., to the vicinity of the westernmost projection of the continent at Point Pariña (4° 40′ S.), whence the main branch sets west-northwestward, flows on both sides of the Galapagos Islands, and is lost beyond longitude 100° W. in the south equatorial drift.

It would seem that the current is most apparent, as a factor to be taken account of by navigators, after it departs from the South American coast. Between Cape Blanco and the Galapagos Islands, Fitzroy, commander of the *Beagle* "was set fifty miles to the west-northwest" in the twenty-four hours preceding his making the archipelago from the southeast.[4] In the same region Colnett "fell in frequently with streams of current, at least a mile in breadth, and of which there was no apparent termination. They frequently changed the ship's course, against her helm, half the compass, although running at the rate of three miles and an half an hour. . . . The

[4] Robert Fitzroy: Narrative of the Surveying Voyages of His Majesty's Ships Adventure and Beagle, 3 vols., London, 1839; reference in Vol. 2, p. 505, footnote.

froth and boil of these streams appear at a very small distance like heavy breakers."[5] Further evidence of the activity of oceanic circulation about the Galapagos is afforded by one of Fitzroy's observations, made in October, 1835, when surface temperatures on opposite sides of Albemarle Island were found to be respectively 80° F. and less than 60° F.[6]

In addition to the main or westerly branch of the Humboldt Current, a minor effluent, which turns northeastward after passing Point Pariña and flows along the Ecuadorian coast into the Bay of Panama, is apparent at certain seasons.

Thermal Characteristics of the Humboldt Current

Significant thermal features of the surface waters in the littoral portion of the current, with which this paper is concerned, are (1) relatively low temperatures in close proximity to the land, with rising temperatures off shore along lines perpendicular to the trend of the coast; and (2) extraordinary uniformity of temperatures throughout the greater part of the length of the current, a uniformity which is little affected by either latitude or season of the year. Both of these facts would of themselves strongly suggest that the low temperatures close to shore are due to upwelling from the "polar creep" rather than to the actual northward transportation of subantarctic surface waters. The conditions are totally unlike those of warm currents, such as the Gulf Stream and the Brazil Current, which undoubtedly carry identical masses of water for great distances. It must be borne in mind that oceanic streams of the latter type are in their entirety surface flows, which usually if not always rest upon layers of colder and denser waters.

The researches of McEwen[7] have made it clear that the low surface temperatures in the inshore areas of the California Current are due exclusively to upwelling of bottom water caused by the broad belt of northwesterly winds along the Pacific coast of North America. Such winds, acting upon a principle previously referred to, cause the moving surface water to swing gradually toward the right, or off shore, whereupon it is replaced by water from deeper layers. In like manner south of the equator an accelerated left-hand trend and continuous vertical circulation are caused in the Humboldt Current by steady southerly winds, parallel to the coast, which tend to force the surface water off shore at an angle of 45° from their path. For the same reason and also because the submarine slope of the continent shoulders off to seaward the warmer and lighter surface waters of a deep, impinging stream, the water closest to shore is the coldest. The steeper the coastal slope, the greater the reduction of surface temperature, for the narrower and more concentrated is the belt of upwelling bottom water.

[5] James Colnett: A Voyage to the South Atlantic and Round Cape Horn into the Pacific Ocean, London, 1798, pp. 45–46.

[6] Fitzroy, *op. cit.*, p. 505.

[7] G. F. McEwen: The Distribution of Ocean Temperatures along the West Coast of North America Deduced from Ekman's Theory of the Upwelling of Cold Water from the Adjacent Ocean Depths, *Internatl. Rev. der gesamt. Hydrobiol. und Hydrogr.*, Vol. 5, 1912, pp. 243–286.

During five months' field work in 1919 and 1920, the writer recorded upwards of 300 surface temperature observations in the Humboldt Current at points between Independencia Bay (14° 18′ S.) and the northern waters of Peru (4° S.).[8] Although many of the readings proved slightly higher than ranges obtained during the earlier and more extensive work of Coker,[9] the general conclusions of the latter were confirmed. These are (1) that only very slight latitudinal changes in the surface temperature of the inshore coastal water occur along the whole length of the Peruvian coast between Mollendo and Paita (1000 nautical miles) and (2) that the small observable variations are due chiefly to local influences and only in much slighter degree to seasonal conditions.

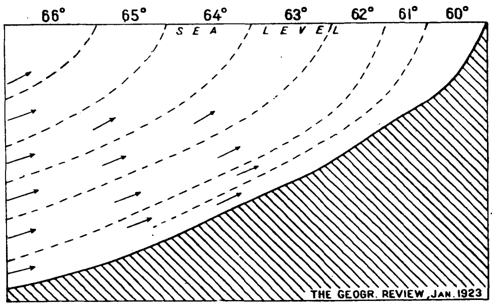

FIG. 1—Diagram illustrating the probable relation between the upwelling of bottom water and decreasing shoreward temperatures in the Humboldt Current (width of cross section approximately 10 sea miles). For a discussion of parallel conditions on the west coast of Africa see Alfred Franz: Beiträge zur Ozeanographie und Klimatologie der Deutsch-Sudwestafrikanischen Küste nach Beobachtungen von S. M. S. *Möwe*, *Archiv der Deutschen Seewarte*, Vol. 38, No. 1, 1920.

Earlier investigators[10] than Coker have established the fact that the uniform temperature conditions of the Peruvian coast are carried southward in the Humboldt Current at least as far as Valparaiso, Chile. It is in accord with the abyssal topography that the current, as characterized by upwelling waters, should begin near Valparaiso, for just south of that port the great bank on which Juan Fernandez lies extends to the westward more than twenty degrees of longitude.

TEMPERATURE FLUCTUATIONS IN THE CURRENT

Average temperatures within five miles of shore along the greater part of the coast of Peru range between about 58° F. (14.44° C.) and 64° F. (17.78° C.) throughout the year. At times, however, irregular variations are apparent locally, or even extensively, such changes being commonly attributed to a shifting of the course of the Humboldt Current, that is to influences which cause the stream to swing temporarily off shore. This assumed phenomenon, mentioned by Coker, is universally accepted as a fact in Peru. The alleged aberrations are recognized by the native fishermen through the effect upon

[8] The instruments used were among equipment generously supplied by the American Geographical Society and comprised United States naval thermometers (Fahrenheit) and specially constructed maximum and minimum thermometers of Six's type, all manufactured and calibrated by the Henry J. Green Co.

[9] R. E. Coker: Ocean Temperatures Off the Coast of Peru, *Geogr. Rev.*, Vol. 5, 1918, pp. 127–135.

[10] Otto Krümmel: Handbuch der Ozeanographie, 2nd edit., 2 vols., Stuttgart, 1907 and 1911; reference in Vol. 2, p. 715 (quoting observations by Capt. Paul Hoffmann).

J. Y. Buchanan: On the Similarities in the Physical Geography of the Great Oceans, *Proc. Royal Geogr. Soc.*, Vol. 8, 1886, pp. 753–770; reference on p. 765.

the catch of anchovies, bonitos, or other fishes;[11] and by the inhabitants of coastal towns through the effect upon climate. Exceptionally warm weather at Lima—such as obtained, for example, during part of the winter season (June-Sept.) of 1919—is credited in popular opinion to the retreat of the current from the coast.

It is the writer's belief that such phenomena are to be interpreted in another way. Many observers, from the days of Fitzroy to the present, have noted that an alteration or reversal or "set to southward" in oceanic circulation along the Peruvian coast is likely to occur from time to time and that such changes often coincide with or follow northerly winds. We have abundant evidence that the friction between atmosphere and hydrosphere produces a quick response. The normal conditions in the Peruvian littoral are due to prevailing southerly winds which, except for the well known day and night swing, vary remarkably little from one year's end to another. When, however, this uniform meteorological control temporarily gives way to northerly winds there is a tendency to drive the warmer offshore surface waters towards the land at an angle of 45°, and an immediate effect is seen in the partial or complete cessation of upwelling. Moreover, the fact that the calculated eastward pressure of the Humboldt Current is literally blocked by the half-submerged Andean wall, makes the explanation just given more satisfactory than the pure assumption that the current sometimes shifts its course to westward, an assumption which has perhaps been made through false analogy with the very different hydrographic system of the Atlantic Gulf Stream.

The Countercurrent

Paracas Peninsula and San Gallan Island (13° 50′ S.), which project into the Pacific at the "bend" of the Peruvian coast, appear to mark the boundary between two littoral regions of somewhat different oceanographic character. To the southward of this point conditions in the coastal water which depend in the main upon constant upwelling attain their maximum of uniformity;[12] to the northward the generally stable equilibrium is at times disturbed not only by such relatively insignificant fluctuations as have already been referred to but also by influences of a more profound nature. Especially to the northward of Salaverry (8° 13′ S.), seasonal influxes of warmer waters from equatorial regions sometimes raise the temperatures considerably above normal over wide areas. The advancing tropical waters form an indubitable countercurrent, which is known to the inhabitants of the coast as *El Niño* (The Child) because it often becomes evident about Christmas time.

This countercurrent, which Coker has described,[13] made its appearance at the time of the writer's field work among the northern Peruvian islands, in January, 1920. On the second of this month, the average of 11 surface tem-

[11] Coker, Ocean Temperatures, p. 132.

[12] Coker, *ibid.*, p. 133, found absolutely no seasonal variation in surface temperatures on an exposed shore at Mollendo.

[13] *Ibid.*

peratures taken during a period of six hours off Pacasmayo (7° 24′ S.) was 60.4° F. (15.78° C.). Two weeks later (Jan. 15 and 16), however, 17 temperatures obtained during 28 hours in the same area averaged approximately 69° F. (20.56° C.). The explanation is that the warm waters of *El Niño* had overflowed the northern end of the Humboldt Current in the interim.

The countercurrent has long been an object of interest to navigators and other observers in Peru. It has been discussed in many issues of the *Boletín* of the Geographical Society of Lima, beginning with the first volume in 1892, and its imperfectly known characteristics are recorded in the Peruvian *derroteros*, or pilot books, of Melo and Stiglich. Stiglich[14] and other Peruvian writers infer that the countercurrent proceeds from the river Guayas (emptying into the Gulf of Guayaquil) in freshet season, but the volume of water in this source would be insufficient to account for the observed effects. The current should be attributed rather to the periodic even though variable changes in barometric pressure which occur when the belt of maximum insolation is well south of the equator.

Aside from the previously noted increase of ocean temperatures off Pacasmayo, the writer's field notebook contains numerous inferential references to the southward extension of *El Niño* in January, 1920. Among these are the following:

1. The captain of the Chilean steamship *Huasco* testified that on January 10, while passing northward between the Lobos Islands (6° 27′—6° 56′ S.), the course of his vessel was perceptibly affected by a strong northwestward set of the Humboldt Current. On the following morning, however, off Sechura (5° 35′ S.) he encountered an adverse current, flowing southward past Paita and noticeable thereafter along the entire length of the coast of Ecuador.

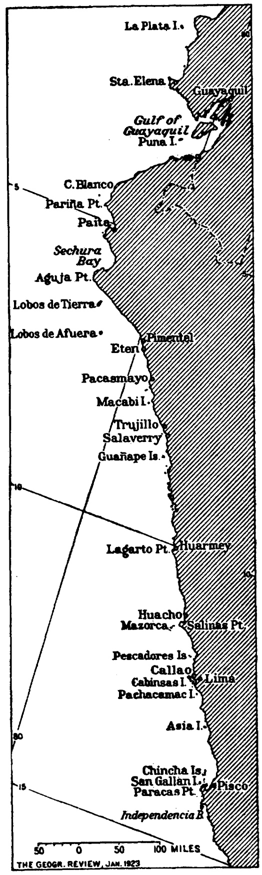

FIG. 2—Sketch map of the Peruvian coast to show localities mentioned in the text.

2. On January 24, near the Guañape Islands (8° 35′ S.), when the temperature of the surface of the ocean was 67.5° F. (19.72° C.), or from 6 to 7 degrees higher than it had been on January 1, many *mantas*, or large rays,[15] were seen leaping from the water into the air. Ordinarily these somersaulting fishes are to be observed only in the extreme northern waters of Peru, north of Point Pariña. Their jumping is a common phenomenon in the tropical ocean off Ecuador. Near La Plata Island (1° 16′ S.), for instance, the writer noted them in great abundance on September 5, 1919, and again in early February, 1920. The commander of the *Huasco* (Captain Herbert Gregory) maintained that the migration of the jumping rays down the Peruvian coast as far southward as Salaverry and the Guañapes is always coincident with other manifestations of *El Niño*.

[14] Germán Stiglich: Derrotero de la costa del Perú, Lima, 1918, p. 8.

[15] It has not been possible, in default of specimens, to identify this large and conspicuous species.

3. On January 24 large numbers of dead boobies, of a species (*Sula variegata*) which lays its eggs on the ledges of the Peruvian islands, were observed along scummy drift lines extending for miles to the *southward* of Macabi and Guañape Islands. Ordinarily the lines of foam produced by the rocks and islets of the coast stretch away to the northward, and the dead birds, chiefly nestlings which have fallen from the cliffs, are carried rapidly in the same direction by the flow of the Humboldt Current.

The problems of the countercurrent have recently been attacked by Lavalle[16] in relation to a peculiar pandemic disease of the Peruvian guano birds, which he has diagnosed as "aspergilosis." This malady appears at intervals of years, and its visible effects have been mentioned from early times in maritime books and in the logs of ships.[17] During the outbreaks countless numbers of the littoral sea birds die upon the breeding grounds or the water, their bodies subsequently washing ashore by thousands and strewing the beaches for miles.

Lavalle attributes the disease of the birds, together with the meteorological and hydrographic changes which ordinarily precede its appearance, to the southward advance of *El Niño*. After calling attention to the fact that the temperature of the tropical current is normally not less than 5° C. higher than that of the most northerly waters of the Humboldt Current near Cape Blanco, he remarks that fish and nearly all forms of plankton are killed by abrupt temperature changes of this magnitude. Correlating his hypothesis with phenomena observed in 1917 or recounted in the literature of the subject, Lavalle evolves a rational exposition of the relation between the advance of the countercurrent, accompanied by changes in ocean temperature, atmospheric humidity, etc., and its secondary effects such as the mortality of fish and birds and the irruption of the renowned "Callao Painter." The latter phenomenon, which is known also as "*aguaje*" and "*agua enferma*," is in general confined to the stretch of water between Paita (5° 05′ S.) and Pisco (13° 43′ S.), and more especially to that between Pacasmayo (7° 24′ S.) and Callao (12° 04′ S.). Its immediate cause, according to Lavalle, is the accumulation of enormous quantities of plankton, killed by the rise of ocean temperatures, in protected localities where, owing to the coastal contour, centripetal eddies exist. The bay of Callao is one of several such places. Here the penetration of the sun's rays into the shallow water hastens decomposition of the mass of organisms, which are so thick as to discolor the ocean. Active production of hydrogen sulphide and other gases results, and for a while the affected areas become as toxic to life as the depths of the Black Sea.[18]

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16 J. A. de Lavalle: Informe preliminar sobre la causa de la mortalidad de las aves ocurida en el mes de marzo del presente año, *Memoria de la Compañía Administradora del Guano*, Vol. 8, 1917, pp. 61–84.

17 Rear Admiral C. F. Goodrich, U. S. N., has informed the writer that on August 10 and 11, 1899, the U. S. S. *Newark*, under his command, passed for three hundred miles through areas of dead pelicans and other sea birds in the northern waters of Peru. The position of the vessel at noon of August 11 was 5° 07′ S. (off Paita), 45 miles from the coast.

18 W. E. Allen (Problems of Floral Dominance in the Open Sea, *Ecology*, Vol. 2, 1921, pp. 26–31) has recently directed attention to the extreme sensitiveness of diatoms and other marine organisms to changes in salinity, light, density, temperature, and hydrogen-ion concentration and to the possibilities of sudden, excessive, and finally fatal development of one or more species of organisms to the exclusion of other related or competing forms.

It is easy to understand the effect of the countercurrent upon the piscivorous sea birds of the Peruvian coast. Lavalle[19] states that in March, 1917, before *El Niño* had become perceptible about the Guañape Islands but after it had been reported farther to the northward, great numbers of pelicans arrived at Guañape, having abandoned their feeding grounds in the neighborhood of the Lobos Islands at the approach of the warmer water. Shortly afterwards the total sea bird population of Cabinsas (12° 09′ S.) fled in like manner from their threatened territory and settled at Pachacamac and Asia Islands (respectively 12° 19′ S. and 12° 48′ S.). The ultimate fate of all birds which do not migrate in this way to the "safe" waters of the southern half of the Peruvian coast is a loss of food supply and a lowering of vitality which renders the victims an easy prey to infectious pulmonary disease caused by a fungus, *Aspergillus fumigatus*, or by related organisms. If the countercurrent continues its advance as far south as the Pisco Bay region, hundreds of thousands of the priceless guano birds may perish before the rhythms of nature restore favorable life conditions throughout the field of the Humboldt Current.

Evidence as to the Prevailing Uniformity of Hydrographic Conditions in the Current

It should not be forgotten that cataclysmic disturbances, such as have just been described, obtain at only rare intervals and are the exception rather than the rule. Extraordinary uniformity is, after all, the outstanding hydrographic feature of the Peruvian littoral. The very fact that relatively slight fluctuations toward the border line of a distinct oceanic region so profoundly affect the whole life association of the Humboldt Current is in itself evidence that this life must have become thus inflexibly adapted through the long duration of substantially invariable conditions.

Essential uniformity in the Humboldt Current is indicated by temperature data alone, but confirmation drawn from a study of the diatomaceous flora may serve to emphasize the prevailing physical stability.

Townet collections obtained by the writer, together with samples of bird guano of various ages and from several different islands in the Humboldt Current, were submitted to Dr. Albert Mann, of the Carnegie Institution, who has reported by letter upon their diatom content. Some of the guano samples were excavated in deep, so-called "fossil" beds on Lobos de Afuera and Lobos de Tierra, where it must have been deposited so long ago that its age can be reckoned only by centuries. Both the ancient and the recent guano, as well as the plankton collected in townets along some 700 miles of the coast, proved to be rich in diatoms. The point of particular interest is that all of this material, whether collected in October or in February, whether at Independencia Bay (14° 15′ S.) or near the Lobos Islands (7° S.), whether captured in the haul of a silk net or extracted from guano deposited by four

[19] Informe preliminar, p. 22.

or more species of sea birds an hour, a month, a year, or five hundred years before—contained the same characteristic species of diatoms. Certain prevalent forms, such as *Skeletonema costatum*, *Grammatophora marina*, and various species of the genus *Coccinodiscus*, appear in nearly all of the diverse samples which were analyzed. Dr. Mann writes:

> There is considerable similarity between the different guanos in the species of diatoms they contain. In fact no sample stands out as radically unlike the rest, as would be the case were the plankton flora of the ocean a totally dissimilar one at any of the periods of time represented by any one of the samples. This in itself is interesting; because it is no infrequent thing for the diatom flora of a given locality to be strikingly dissimilar on two successive years. Thus the diatoms of Woods Hole, Massachusetts, were very different in 1920 from those found in 1919.[20]

Temperature Ranges in the Humboldt Current

The lowest surface temperature recorded by the writer at stations between Independencia Bay and the Gulf of Guayaquil was 58° F. (14.44° C.), a figure obtained at various times and places. In order to indicate the constancy of upwelling along a great extent of coast, it will be useful to cite the entire list of readings of 60° F. (15.56° C.) or lower.

The lowest temperature readings were obtained close to mainland or insular shore lines and in situations open to free circulation such as the *boquerones* or straits south of Callao and Pisco, the exposed southern entrance of Independencia Bay, etc. In passing from the sheltered waters of Pisco Bay through the constricted *boqueron* which separates Paracas Peninsula from San Gallan Island, surface temperatures in November, 1919, were found to decrease ten degrees Fahrenheit, or from 68° F. (20° C.) to 58° F. (14.44° C.).

Distance from the land, or in any direction away from an exposed islet in the Humboldt Current, is usually concomitant with increase of surface temperature. When traveling parallel with the mainland coast, a mile or more off shore, an observer finds that water temperatures are likely to be lower abreast of a projecting headland than they are off a bight. In short, the lines of equal temperature follow the turnings of the coast line, and a boat bound along shore repeatedly cuts the isothermic curves. Such observations indicate that the upwelling waters are being continually deflected to seaward as they strike exposed bottom slopes of the continental shelf.

The relation between temperature and distance from the Peruvian coast is well shown in Tables II–IV.

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[20] More recently Albert Mann (The Dependence of the Fishes on the Diatoms, *Ecology*, Vol. 2, 1921, pp. 79–83) has published notes which, by contrast, serve to stress still further the perhaps unique uniformity of the diatom flora in waters along the coast of Peru. Referring to conditions which hold for most parts of the world, he writes that there are clearly marked zonal and local diatom floras and that great variation in the constitution and abundance of this element of the plankton occurs from year to year. "Thus the diatom combination of Beaufort, N. C., is easily distinguished from that of Woods Hole, Mass., while that found along the shores of Florida is even more dissimilar." It may be added that the Peruvian coast line, where such variations are not found, is not greatly shorter than the Atlantic coast of the United States.

TABLE I—TEMPERATURE READINGS OF 60°F. (15.56°C.) OR BELOW

Day	Hour	Place	Temperature	
			°F.	°C.
Oct. 8	9 A. M.	Huacho Bay	59.5	(15.28)
	10 A. M.	Huacho Bay	59.6	(15.33)
	1 P. M.	N. end of Salinas Promontory	59.0	(15.00)
	1:30 P. M.	N. E. of Mazorca Island	59.8	(15.44)
16	12 M.	Chincha Is. (Central I.)	58.0	(14.44)
	6 P. M.	Chincha Is. (Central I.)	59.1	(15.05)
17	8 A. M.	Chincha Is. (Central I.)	60.0	(15.56)
	1 P. M.	Chincha Is. (South I.)	59.0	(15.00)
18	8 A. M.	Chincha Is. (Central I.)	60.0	(15.56)
19	10:20 A. M.	N. W. of Paracas Point	59.2	(15.11)
	10:55 A. M.	½ mile N. of Paracas Point	60.0	(15.56)
Nov. 10	7:45 A. M.	Chincha Is. (Central I.)	60.0	(15.56)
	8:07 A. M.	Chincha Is. (Central I.)	59.4	(15.22)
	9:10 A. M.	Point Lastre, Paracas Bay	59.6	(15.33)
15	11:40 A. M.	N. W. of Paracas Point	58.0	(14.44)
	12:10 P. M.	E. of San Gallan Island	58.0	(14.44)
	12:35 P. M.	Boqueron of San Gallan I.	58.5	(14.72)
15–19		Independencia Bay (minimum tube)	58.8	(14.89)
26	10:25 A. M.	N. bight of San Gallan I.	60.0	(15.56)
Dec. 12	11:50 A. M.	Callao Bay	59.8	(15.44)
15	8:15 A. M.	Pescadores Island	59.5	(15.28)
	8:30 A. M.	Gallinazo Islet, Pescadores group	60.0	(15.56)
Jan. 2	1:10 P. M.	1 mile off Pacasmayo	59.8	(15.44)
	1:18 P. M.	¼ mile off Pacasmayo pier	59.5	(15.28)
2, 3		Pacasmayo anchorage (minimum tube)	58.2	(14.56)

TABLE II—DECREASING TEMPERATURES OBTAINED WHILE BOUND TOWARD SHORE AT HUARMEY (10° 06′ S.), DEC. 30, 1919

10:30 A. M.	10 miles S. W. of Lagarto Head	67.0° F.	(19.44° C.)
11:30 A. M.	8 miles W. by S. of Lagarto Head	65.0	(18.33)
12:30 P. M.	5 miles off Lagarto Head	63.8	(17.67)
1:25 P. M.	Rounding Lagarto Head (entrance to Huarmey)	61.6	(16.44)

TABLE III—DECREASING TEMPERATURES OBTAINED WHILE APPROACHING LOBOS DE TIERRA FROM THE SEAWARD SIDE, JAN. 6, 1920

12:05 P. M.	8 miles from Lobos de Tierra	69.0° F.	(20.56° C.)
1 P. M.	4 miles from Lobos de Tierra	68.1	(20.05)
1:50 P. M.	2 miles from Lobos de Tierra	67.7	(19.83)
2:30 P. M.	1 mile from Lobos de Tierra	66.0	(18.89)
3:20 P. M.	At anchor, Caleta de Cherra	65.5	(18.61)

It would appear that Lobos de Tierra, the largest of the Peruvian islands, simulates the continent in producing upwelling from lower layers of water.

On January 15 and 16, 1920, after the mingling waters of *El Niño* had raised the general level of surface temperatures off northern Peru, a series of 17 readings, taken along an oblique line across the normal path of the Humboldt Current, still showed a gradual decrease from 70.2° F. (21.22° C.) one-half mile east of Lobos de Tierra to 66.5° F. (19.17° C.) near the end of the pier at Eten (6° 56′ S.).

TABLE IV—INCREASING TEMPERATURES OBTAINED WHILE BOUND FROM PACASMAYO TO LOBOS DE AFUERA ISLAND, JAN. 3 AND 4, 1920

6 P. M.	Pacasmayo (28 hour minimum)	58.2° F.	(14.56° C.)
9 P. M.	11 ? miles off shore	61.5	(16.39)
6:30 A. M.	21 ? miles E. S. E. of Lobos de Afuera	66.2	(19.00)
7:10 A. M.	18 ? miles E. S. E. of Lobos de Afuera	66.5	(19.17)
7:35 A. M.	16 ? miles E. S. E. of Lobos de Afuera	66.7	(19.28)
8:45 A. M.	12 miles E. by S. of Lobos de Afuera	67.0	(19.44)
9:30 A. M.	8 miles E. by S. of Lobos de Afuera	67.2	(19.56)
10:20 A. M.	4 miles E. by S. of Lobos de Afuera	68.0	(20.00)
10:35 A. M.	3 miles E. by S. of Lobos de Afuera	68.0	(20.00)
10:50 A. M.	1 mile from Lobos de Afuera	69.0	(20.56)
11 A. M.	Anchorage ¼ mile from shore	68.7	(20.39)

Again, on February 3–7, 1920, temperatures of 66.2° F. (19.00° C.) close to the beach at Salaverry increased steadily off shore and to the northward, reaching 75.2° F. (24.00° C.) near Point Pariña (4° 40′ S.) on February 4, 79° F. (26.11° C.) off the Gulf of Guayaquil, and 80° F. (26.66° C.) off Point Santa Elena (2° 12′ S.), Ecuador. The last two figures are close to the yearly mean temperature not only of the Ecuadorian littoral but also of the offshore waters of the southern tropical Pacific, outside the zone of upwelling, at least as far to the southward as the latitude of central Peru (e. g. 14° S.). Captain Paul Hoffmann[21] found, for example, that surface temperatures of 64.9° F. (18.3° C.) at Callao rose progressively to 81.0° F. (27.00° C.) at 135 nautical miles from shore. Data from the *Albatross* records of 1904, quoted in substance by Coker,[22] further support the conclusions which must be drawn.

By bringing together available thermometric readings accompanied by exact locations the writer has computed that 1.5° F. represents an approximation of the average rise in temperature per nautical mile from the coast line of central and northern Peru. The rate would not, of course, apply during an active advance of the countercurrent. Moreover, because of the paucity of the observations and the fact that the ratio between temperature and distance is unlikely to be constant across the full width of the Humboldt Current, the figure can be considered as only suggestive.

[21] Paul Hoffmann: Zur Mechanik der Meeresströmungen an der Oberfläche der Oceane, Berlin, 1884, p. 76.
[22] Ocean Temperatures, p. 130.

As regards normal maximum temperatures in the Humboldt Current, the data are rather difficult to interpret because most of the high readings can be attributed to special circumstances. Great variation occurs, as Coker has pointed out, in enclosed bays, where eddies form and where the same masses of shallow water lie until they can be warmed by the sun. Doubtless the best conception of average high temperatures will be derived from considering a series of records from exposed situations, such as the Chincha Islands or the Guañape and Lobos Islands before the surrounding waters had been warmed by the countercurrent of January, 1920.

Ranges of surface temperatures at fixed points, with data on diurnal and nocturnal variation, are given in Table V, which comprises readings obtained with both the Six's and the naval thermometers.

TABLE V—TEMPERATURE RECORDS IN THE HUMBOLDT CURRENT, OCTOBER, 1919—FEBRUARY, 1920

DATE	PLACE	RECORD	LOWEST		HIGHEST	
			°F.	°C.	°F.	°C.
1919						
Oct. 11	Central Chincha Is.	24 hours	63.2	(17.3)	65.0	(18.3)
Oct. 13	Central Chincha Is.	48 hours	60.8	(16.0)	61.2	(16.2)
Oct. 14	Central Chincha Is.	22 hours	59.0	(15.0)	63.7	(17.6)
Oct. 16	Central Chincha Is.	2 readings, 12 M., 6 P. M.	58.0	(14.4)	59.1	(15.0)
Oct. 17	Central Chincha Is.	3 readings				
Oct. 18	Central Chincha Is.	4 readings, 8 A. M., 3 P. M.	60.0	(15.5)	63.1	(17.3)
Oct. 21	Central Chincha Is.	4 readings, 8 A. M., 3 P. M.	63.7	(17.6)	64.9	(18.3)
Oct. 24	Central Chincha Is.	2 readings, 8 A. M., 6 P. M.	63.0	(17.2)	63.8	(17.7)
Oct. 25	Central and North Is. (4 stations)	4 readings, 8 A. M., 10 A. M.	61.4	(16.3)	63.9	(17.7)
Oct. 26	Central Chincha Is.	3 readings, 8 A. M., 1 P. M.	62.0	(16.7)	63.3	(17.4)
Nov. 22	Central Chincha Is.	4 readings, 6:30 P. M., 2:30 P. M.	64.5	(18.0)	65.3	(18.5)
Nov. 23	Central and North Is. (6 stations)	6 readings, 9:30 A. M., 8:30 A. M.	62.8	(17.1)	63.8	(17.7)
Nov. 26	North Chincha Is.	48 hours	60.8	(16.0)	62.3	(16.8)
Nov. 15–19	Independencia Bay	84 hours	58.8	(14.9)	63.6	(17.5)
Dec. 28	Palominos Rocks (off Callao)	3 readings, 2:30 P. M., 7:15 P. M.	62.0	(16.7)	63.0	(17.2)
1920						
Jan. 1	South Guañape Is.	24 hours	60.8	(16.0)	63.3	(17.4)
Jan. 3	Pacasmayo (anchorage)	28 hours	58.2	(14.5)	60.8	(16.0)
Feb. 1	Bay of Callao	2 readings, 11 A. M., 6:30 P. M.	63.6	(17.5)	64.0	(17.8)

Records made with the maximum-minimum thermometer at Independencia Bay and elsewhere show that the average of maxima for the day period (7 A. M.—7 P. M.) is about 2° F. higher than the average maxima for the night period. For additional data on these very slight changes, which are a further indication of upwelling, Coker's paper should be consulted.

Readings of from 68° F. (20.00° C.) to 69° F. (20.56° C.) were made in parts of the Bay of Pisco during October and November; but these were in every case explained by the discharge of freshet waters from the Pisco River, which turned toward the left or south from its mouth and formed a counterclockwise eddy distinguishable from the bay water by color as well as by temperature. Similar phenomena, with increases of temperature amounting to 6° or 7° F., were noted on February 3, off the mouth of the River Chicama, north of Salaverry. With these exceptions, no temperature higher than 66° F. (18.89° C.) was obtained within twelve miles of the Peruvian mainland until after the first signs of *El Niño* in January. It need hardly be added, however, that high temperatures were recorded everywhere *off shore* during the whole period of field work.

The Breadth of the Humboldt Current as Compared with That of the California Current

Stiglich[23] states that the mean breadth of the Humboldt Current along the coast of Peru is about 150 miles, a figure which, from a navigator's point of view, is doubtless roughly correct. We have records of very few temperature observations along lines extending across stream to the warm outlying ocean, but the *Albatross* tables[24] and the readings of Captain Hoffmann show that the belt of cool water is extraordinarily narrow when compared with conditions in the corresponding region of the North Pacific. The fact is confirmed, furthermore, by studies of the biota of the Humboldt Current, for the characteristic algae, as well as the invertebrates, fishes, and higher forms of life, are all confined to waters near the coast.[25]

Recent investigations in the California Current by the hydrographic staff of the Scripps Institution for Biological Research reveal an order which is at striking variance with that of the Peruvian littoral. The California Current, at least off the southern Pacific coast of the United States, is a remarkably broad stream, the effects of which can be detected a thousand or more miles from shore. Again, the zone of maximum upwelling, and consequently of lowest temperatures and greatest profusion of marine life, lies far off the coast, in sharp contrast with the respective conditions off the west coast of South America. Michael[26] sums up the data for the California Current as follows:

Between July, 1917, and June, 1918, and within a strip of water extending approximately one hundred twenty-five nautical miles seaward from Point Fermin, volume of phytoplankton, collected in vertical hauls from 200 meters to the surface, when corrected for the effect

[23] *Op. cit.*, p. 8.

[24] *Bur. of Fisheries Doc. No. 604*, 1906, pp. 54–58.

[25] Estimates of the breadth of the Humboldt Current as deduced from meteorological observations conform with those based upon other data. Cf. Mark Jefferson: The Rainfall of Chile, *Amer. Geogr. Soc. Research Ser.*, No. 7, 1921, p. 8.

[26] E. L. Michael: Effect of Upwelling Water upon the Organic Fertility of the Sea in the Region of Southern California, *Bernice P. Bishop Museum Special Publ. No. 7, Part II*, 1921, pp. 555–595; reference on p. 589.

of season, increased, on the average, from a minimum nearest shore to a maximum about seventy miles off and then decreased with further increase in distance.

The surface temperature, simultaneously observed at the places phytoplankton was collected, decreased on the average, when corrected for the effect of season, from a maximum nearest shore to a minimum about seventy miles off and then increased with further increase in distance.

The explanation of these contrasts, which are at first puzzling, is doubtless to be found in the very different relative trends of the Pacific coast lines of North and South America and in the dissimilar topography of the respective continental shelves. A glance at the map, especially at a globe, will show the great divergence of the coasts of the Californias from the course of the clockwise, or right-hand, southward-flowing current. The coast of Peru, on the contrary, trending sharply to westward from near the Chilean border, extends far into the ideal course of the Humboldt Current and forces the latter to become an actively impinging stream until it has passed the end of the continental buffer at Point Pariña. A bathymetric chart throws further light on factors which produce dissimilar zones of upwelling in the two hemispheres. The South American coastal shelf, between Valparaiso and northernmost Peru, is narrower, more steeply terraced, and far less irregular along its outer border than the west coast of North America. Since upwelling is most pronounced where the transition from deep to shallow water is most abrupt, the reason for the low ocean temperature very close to the Peruvian coast is obvious.

The Velocity of the Humboldt Current

Existing data on the rate of flow of the Humboldt Current have been derived mostly from the reports of seafarers whose reckonings have been thrown out by this disconcerting and largely unmeasurable factor. The pilot books rather vaguely assign a velocity of "15 miles per day," a "general set of ½ to 1 knot," "a speed of one mile per hour throughout the year," etc. The effect of the flow is, of course, universally recognized as favorable or adverse in navigation, depending upon the direction of a voyage.[27]

The writer made numerous attempts to measure the rate of flow with a Gurley current meter. Many of the trials were fruitless because the revolutions of the instrument, suspended from one to fifty feet beneath the surface of the sea, were affected by unavoidable jerky movements of an anchored trawler or schooner. The following three readings, each based upon from 6 to 26 counts, were made under generally favorable circumstances. The rates, especially the second and the third, are believed to be not far from approximations of the truth. They are offered here for whatever they may be worth.

1. ½ mile west of South Chincha Island, Oct. 17, 1919. Average of 6 measurements of one minute each. Current of 1.4 statute miles per hour, setting toward the coast (considerably to east of north). The sea was choppy, probably causing an acceleration of the

[27] Coker, Ocean Temperatures, p. 132.

beats of the instrument, so that this reading is considered less dependable than those which follow.

2. Middle of southern entrance of Independencia Bay (Serrate Channel), Nov. 16, 1919. Average of 17 measurements of one minute each. Current of .64 statute miles per hour, setting 45° west of north. The ocean was calm and the station fully exposed to the movement of the current. The beats of the electric indicator were regular, and all indications are that the computation is reliable.

3. 250 yards east of the south point of South Guañape Island, Jan. 6, 1920. Average of 26 measurements of one minute's duration. Current of .7 statute miles per hour, setting 30° west of north. Ocean calm; open sea toward the source of the flow. This is probably the least inaccurate of all the records.

The average of the three velocities is .91 statute miles per hour. The writer has no data as to a possible tidal influence in any of the measurements, but it is not likely to have been significant.

Captains of *caleteras*, or coastwise steamers which call at all the Peruvian ports, informed the writer that the current is a factor to be seriously considered in steamship navigation only in two parts of their route: the first along the southerly coast of Peru, northward from Mollendo, and the second on the reaches between Eten and Point Aguja, in the north. In the latter region, according to the testimony of one captain, the stream frequently maintains a northwesterly rate of one knot for days together. These reports are in harmony with theory, for we might expect the maximum rate of flow where the coast trends to westward and thus deflects the centrifugal pressure.

Ecology of the Humboldt Current

The geophysical characteristics of the Peruvian littoral offer favorable life conditions for a great profusion of marine organisms. In the first place, the low salinity, due to upwelling of water more or less polar in origin, and more particularly the low temperature facilitate absorption of atmospheric gases and the retention of those produced by the metabolism of oceanic plants and animals. Again, low salinity makes possible the solution or suspension of increased proportions of silica, which, together with nitrogen compounds and phosphoric acid, is among the minimal nutritional elements upon which all life in the sea is ultimately dependent.

The reduction of buoyancy due to lowered salinity is more than made up by the increased viscosity resulting from low temperature, viscosity being the most important property of sea water for inhibiting the descent of minute forms of life to unfavorable levels. Other things being equal, water at a freezing temperature offers twice as much resistance against sinking as water at 77° F.

Finally, the stable temperature of the littoral water, except during the rare invasions of *El Niño*, results in life conditions which are far more uniform than along most of the temperate Atlantic coasts where marked periodicity is the rule.

The organic source of all food in the sea, for abyssal creatures as well as those of the surface strata and of the atmosphere above, is the microscopic plant life, comprising mostly the brown algae (Phaeophyceae), which, obtaining their nitrogen directly from nitrates in the circulation, build up tissue that becomes the food of copepods and other crustaceans, certain fishes, etc., which, in their turn, are devoured by higher animals. In the presence of sunlight the microscopic plants, moreover, assimilate the carbon of carbonic acid and restore the oxygen to solution, thus bettering the conditions for animal life. Under optimum circumstances, the algae may number as many as 40,000 individuals per liter of ocean water.[28] They exist principally in a layer within fifty fathoms of the surface, though they may sometimes penetrate three or four times as far, and their dead remains are uninterruptedly settling into the lightless depths. But vertical circulation, which is continually bringing masses of deeper water to the surface along the inner border of the Humboldt Current, is thereby steadily restoring nutritive substances, in the form of decomposition products such as ammonia, to the upper layer of the ocean. Here, if not directly available for the algae, they may be utilized by nitrifying bacteria and worked over into material which enables the profuse development of plant life to go on. The quantity of phytoplankton varies directly with the amount of upwelled water, and for this reason the marine areas in which ascending currents occur are favored with the most prolific efflorescence of both microörganisms and higher creatures. On the other hand, surface life is always least abundant in anticyclonic or dead-water regions, like the Atlantic Sargasso Sea, where the surface layers continually sink.

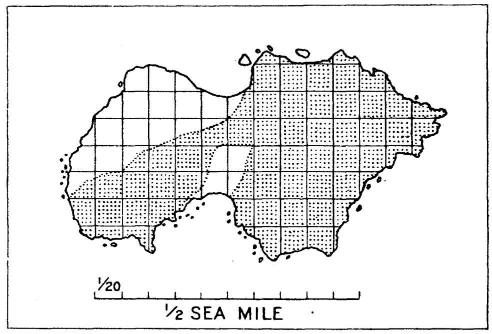

FIG. 3—Sketch map of Central Chincha Island, Pisco Bay, showing in shading the area occupied by *guanayes* or white-breasted cormorants (*Phalacrocorax bougainvillei*) on January 1, 1913. Copied from a manuscript report by H. O. Forbes. A conservative estimate would place the total bird population, young and adult, at 5,600,000. Not less than a thousand tons of fish per day would be required to sustain such a colony.

It has been suggested that another possible effect of the upwelling of cold bottom waters results from the fact that even moderately low temperatures inhibit the activity of denitrifying bacteria.[29] It has been shown, however, that in the presence of sufficient free oxygen these bacteria never exhibit their power of denitrification, even though they may multiply indefinitely.[30] In view of the favorable conditions for the production and retention of oxygen in the cool waters off the west coast of South America, it appears that the suppression of the denitrifying bacteria is here of no great consequence as a partial explanation of the abundant life.

[28] W. E. Allen: Observations on Surface Distribution of Marine Diatoms between San Diego and Seattle, *Ecology*, Vol. 3, 1922, pp. 140–145.

[29] Cf. H. F. Osborn: The Origin and Evolution of Life, New York, 1917, p. 91.

[30] John Murray and Johan Hjort: The Depths of the Ocean, 1912, pp. 369, 370.

Abundance of Life in the Humboldt Current

Thirty-five years ago Buchanan wrote, "No waters in the ocean so teem with life as those on the west coast of South America.[31] More recent investigations have borne out this statement. Space cannot be spared for lengthy quotations relating to the lower animals, but Bigelow's remarks[32] are doubly interesting in that they refer both to the abundance of life in the current and to the contrasting conditions in the warm water areas beyond. He writes:

I cannot pass over without mention the extraordinary richness of the Humboldt Current in pelagic life of all kinds; a richness which has already been noted in the account of the general oceanographic features of the Eastern Tropical Pacific by its [the expedition's] leader, who speaks of "such masses of Salpae, of Cytaeis, or Cymbulia, or swarms of other pelagic animals as to make a thick soup" . . ., and of enormous quantities of copepods, schizopods, Doliolum, and Medusae. Nor can I omit to recall the discovery, immediately to the west and southwest of the Current, of an area as barren in all forms of life, bottom as well as pelagic, as the latter is rich. Thus "As soon as we ran outside of this [the Humboldt Current] the character of the surface fauna changed; it became less and less abundant as we made our way to Easter Island, the western half of the line from Callao becoming gradually barren." On entering the current again from the barren area the reverse change was equally striking.

An impressive picture of the unparalleled profusion of organisms, particularly of fishes and birds, has been given in the publications of Coker, Forbes, Lavalle, Chapman, Murphy, and other writers.[33]

Coker, for example, records the following:

In contrast to the barrenness of the coast [of Peru] there is a peculiar wealth of certain forms in the open ocean. The great red seas, formed sometimes, at least, of myriads of microscopic dinoflagellates, are of common occurrence. . . . Sometimes, too, great areas of the surface of the sea are reddened by the vast numbers of small crustacea (*Munida*),

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[31] Buchanan, *op. cit.*, p. 766.

[32] H. B. Bigelow: Reports of the Scientific Results of the Expedition to the Eastern Tropical Pacific, in Charge of Alexander Agassiz, . . . XVI, The Medusae, *Memoirs Museum of Comp. Zoöl. at Harvard College*, Vol. 37, 1909, p. 222.

[33] The more important references follow:

R. E. Coker: Numerous articles in the *Bol. Minist. de Fomento*, Vols. 5 to 7, 1907–1909, Lima.

Idem: Regarding the Future of the Guano Industry and the Guano-Producing Birds of Peru, *Science*, No. 706, Vol. 28, 1908, pp. 58–64.

Idem: The Fisheries and the Guano Industry of Peru, *Bull. Bur. of Fisheries*, Vol. 28, 1908, Part I, pp. 333–365.

Idem: Habits and Economic Relations of the Guano Birds of Peru, *Proc. U. S. Natl. Museum*, Vol. 56, 1920, pp. 449–511.

Idem: Peru's Wealth-Producing Birds, *Natl. Geogr. Mag.*, Vol. 37, 1920, pp. 537–566.

Idem: An Illustration of Practical Results from the Protection of Natural Resources, *Science*, No. 1370, Vol. 53, 1921, pp. 295–298.

H. O. Forbes: The Peruvian Guano Islands, *The Ibis* (10), Vol. 1, 1913, pp. 709–712 (under "Notes and Discussion").

Idem: Puntos principales del informe presentado al supremo gobierno por el ornitólogo Dr. H. O. Forbes, *Memoria de la Compañia Administradora del Guano*, Vol. 5, 1914, pp. 57–105, Lima.

Idem: Notes on Molina's Pelican, *The Ibis* (10), Vol. 2, 1914, pp. 403–420.

J. A. de Lavalle: Informe preliminar sobre la causa de la mortalidad de las aves ocurida en el mes de marzo del presente año, *Memoria de la Compañia Administradora del Guano*, Vol. 8, 1917, pp. 61–84, Lima.

Idem: Estudio sobre los factores que influyen sobre la distribucion de los nidos de las aves productoras de guano, *ibid.*, 1918, Vol. 9, pp. 207–213.

F. M. Chapman: Notes from a Traveler in the Tropics, III, *Bird-Lore*, Vol. 21, 1919, pp. 87–91.

R. C. Murphy: The Seacoast and Islands of Peru, *Brooklyn Museum Quart.*, Vol. 7, No. 2, 1920 to Vol. 9. No. 4, 1922; especially Part 3, pp. 244–269; Part 4, pp. 17, 18; Part 5, p. 48; Part 8, pp. 64–68.

which then play a part of great importance as food for the fishes and for the guano-producing birds. More striking still are the immense schools of small fishes, the "anchobetas" (*Engraulis ringens* Jenyns), which are followed by numbers of bonitos and other fishes and by sea lions, while at the same time they are preyed upon by the flocks of cormorants, pelicans, gannets, and other abundant sea birds. It is these birds, however, that offer the most impressive sight. The long files of pelicans, the low-moving black clouds of cormorants, or the rainstorms of plunging gannets probably cannot be equaled in any other part of the world. These birds feed chiefly, almost exclusively, upon the anchobetas. The anchobeta, then, is not only . . . the food of the larger fishes, but, as the food of the birds, it is the source from which is derived each year probably a score of thousands of tons of high-grade bird guano. . . . No more forcible testimony to its abundance could be offered than the estimate, made roughly, but with not wide inaccuracy, that a single flock of cormorants observed at the Chincha Islands would consume each year a weight of these fish equal to one-fourth of the entire catch of the fisheries of the United States.[34]

The Distribution of Life as Affected by the Humboldt Current

Next to the extraordinary abundance of marine organisms in low southern latitudes, the predominant zoölogical characteristic of the Peruvian littoral is to be found in the unequaled northward distribution of antarctic or subantarctic types.

Examples to illustrate this fact could be drawn from many subdivisions of the animal kingdom, but the writer will confine his choice chiefly to the higher vertebrates with which, as a systematist, he is familiar. In the category of Peruvian species which are of distinctly austral or subpolar affinities are the following:

1. The southern kelp gull (*Larus dominicanus*), a subantarctic sea bird of circumpolar range, which breeds in numbers in Tierra del Fuego and upon ice-covered, heavily glaciated islands such as South Georgia and Kerguelen, also extends its breeding range along the tropical western coast of South America practically as far as the Humboldt Current is in contact with the land. Its northernmost breeding station, on Lobos de Tierra (6° 25′ S.), is, moreover, *one of its centers of maximum abundance.* On the Atlantic side of the continent the kelp gull apparently nests only south of the Rio de la Plata.

2. The white-breasted cormorant, or *guanay* (*Phalacrocorax bougainvillei*), the first in importance of the Peruvian guano birds, is a member of a well-defined, antarctic branch of the cormorant family. Its close kin are cormorants of the Strait of Magellan, New Zealand, various subantarctic islands, and the shores of the Antarctic Continent, while its relationship with other cormorants of South America or with those of the northern hemisphere is relatively remote. The range of the *guanay* extends along the west coast from central Chile to within six degrees of the equator.

3. Diving petrels (Pelecanoididae), representatives of a typically subantarctic family of marine birds, breed along the western coast from Cape Horn to the northern Peruvian islands (6° 25′ S.). In no other part of the world

[34] Coker, The Fisheries and the Guano Industry of Peru, p. 338.

are diving petrels known to breed north of about latitude 37° S. (viz. at Tristan da Cunha).

4. Penguins (genus *Spheniscus*) occur northward along the west coast to latitude 6° S., and an endemic species (*S. mendiculus*) resides on the Galapagos Islands, which are crossed by the equator.

5. The southern sea lion (*Otaria byronia*) is permanently resident along the west coast from Cape Horn to northern Peru, and a representative of the same genus occurs at the Galapagos.

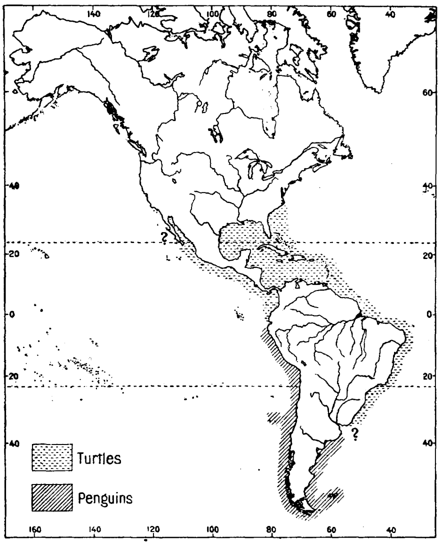

FIG. 4

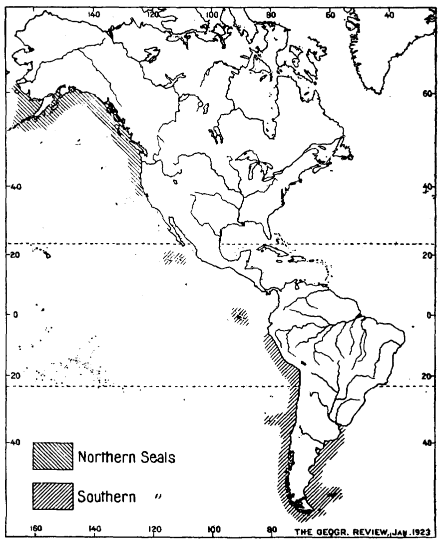

FIG. 5

FIG. 4—Breeding ranges of penguins and of sea turtles, the former determined by low, the latter by high ocean temperatures.

FIG. 5—Ranges of fur seals: the northern genus, *Callorhinus;* the southern genus, *Arctocephalus.* It is noteworthy that no fur seals occur in the warm waters littoral between northern Peru and Lower California.

6. The rare southern fur seal (*Arctocephalus australis*), recently noted by the writer at Independencia Bay, formerly ranged from Cape Horn to northern Peru and the Galapagos, throughout the path of the Humboldt Current. This genus, moreover, has succeeded in "jumping" the northern hydrographic barrier, for a related species (*Arctocephalus townsendi*) is resident off the Lower California coast and may still exist at Guadalupe and San Benito Islands (beyond 28° N.). The latter range, it should be observed, is north of the zone of tropical sea water, in which, of course, no fur seal is to be found.

7. In a similar manner, the southern sea elephant (*Mirounga leonina*) formerly occurred northward along the Chilean and Peruvian coasts to a point now indeterminable. An example has recently been reported from Ilo, Peru. This strange genus of seals reappears, like the fur seal, in the analogous littoral region of the California Current, where the northern form (*M.*

angustirostris) formerly ranged from Cape Lázaro, Lower California (24° 40′ N.) to Point Reyes, north of San Francisco.

In correctly attributing the range of these various animals and of their food supply to the influence of the Humboldt Current, it is easy at the same time to fall into a common error. Thus Boubier,[35] referring to the striking case of the distribution of penguins, states that cold currents not only maintain a low surface temperature and also probably assist in reducing atmospheric temperature (the isotherm of 20° C. roughly limits the distribution of penguins) but, what is more important, they transport an enormous mass of antarctic plankton upon which the birds feed. The organisms constituting this plankton live only in the cold waters, so that when the currents become warmed by traversing tropical seas before returning south (as along eastern coasts of the southern continents), they lose their antarctic plankton. Penguins are accordingly absent from these coasts.

The misconception here is not with regard to the main thesis of penguin distribution but in the idea that low surface temperatures and subantarctic plankton content are due to the transportation of surface water from high latitudes. It has been shown above that the temperature is accounted for by upwelling, which is very marked and very uniform, along great stretches of the western continental coasts. The conception of great "oceanic rivers," bearing northward the cold water and the living cargo of subantarctic seas, is altogether imaginary. The currents are at best extremely lethargic as compared with rivers of the land. The organisms that inhabit them do not originate in the far south, unless it be in an evolutionary sense, but are born, live, and die in the middle or low latitudes where they are found. It is not, in short, that the cold currents carry individual organisms across the temperate zones and into the tropics but rather that the vertical circulation produces life conditions, in narrow littoral belts, which resemble those of antarctic and subantarctic seas. The difference, in actual transporting power, between the deep, cold currents and such rapid surface currents as the Gulf Stream should be emphasized again.

As the Humboldt Current is a narrow stream, it need hardly be added that the composite range of the endemic marine fauna of the Peruvian coast is likewise a narrow ribbon of ocean, hugging the shore and projecting toward the equator from the far south. The facts were first suggested by Ortmann[36] in his studies on the distribution of marine decapods, but the larger implications have been steadfastly ignored by most zoögeographers. If we sail off shore across the current, we encounter a change in fauna which is closely correlated with change in surface temperatures; after a few miles the rich plankton, the sea lions, the penguins, cormorants, kelp gulls, and subantarctic petrels—an aggregate of thousands of species—all disappear. A new oceanic region with a distinctive fauna, rich in species, perhaps, but

[35] M. Boubier: La distribution géographique des manchots (Sphéniscidés) et son interprétation géophysique, *Rev. Française d'Ornithologie*, Vol. 11, 1919, pp. 131–136.

[36] A. E. Ortmann: Grundzüge der marinen Tiergeographie, Jena, 1896.

poor in the relative number of individuals per unit of space, spreads away across the vast expanse of the tropical South Sea.

The hydrographic and biological status of the tropical ocean to the northward of the Humboldt Current is even less well known than that of the Peruvian littoral. Although lying almost entirely north of the equator, this region is in barometric and thermal features the real equatorial belt of the eastern Pacific. The warmest surface temperatures are found north of latitude 5° N., the maximum isotherm moving up toward the Gulf of California during the summer. With the scanty data available, it is impossible to determine the full extent to which this zone acts as a biotic barrier. We have seen, however, that two genera of seals have succeeded in passing it. Recent studies upon the Peruvian littoral fishes,[37] moreover, show that the assemblage has its closest zoölogical affinities with the fishes of the Californian littoral and that both faunae have a pronounced Mediterranean facies.

A type of discontinuous distribution approaching "bipolarity" is produced in certain instances by the oceanic system of the west coast of America. An example is offered by *Emerita analoga*, a small decapod crustacean of the family Hippidae inhabiting a narrow strip of sandy beach within the wash of the waves. The distribution of the species is from Oregon to San Bartolomé Bay, Lower California, and from northern Peru to Chile. The intermediate zone, between Lower California and Ecuador, is occupied, as might be expected, by a tropical species (*Emerita emerita*) which occurs also along warm shores of the Atlantic side.

The antarctic giant kelp (*Macrocystis pyrifera*), the largest of seaweeds, which ranges elsewhere along the western coast of America from Cape Horn to Alaska, has not been reported from a hiatus between Lower California and northern Peru, i. e. the northern and southern points, respectively, at which the effect of cold currents ceases to be considerable. Conversely, this warm belt circumscribes the eastern Pacific breeding range of sea turtles, none of which, so far as the writer has been able to learn, deposits its eggs on beaches south of the Gulf of Guayaquil (3° S.), or north of southern Lower California. On the Atlantic coast the breeding grounds of these chelonians extend from Virginia to southern Brazil or beyond. The sea snakes (Hydrophidae) are likewise confined in their distribution along the western coast of America between 4° S. and 20° N., while the coastal range of crocodilians is entirely between the equator and the Tropic of Cancer. Finally, the distribution of reef corals along the Pacific coast is limited to the region between 4° N. and 21° N., whereas on the Atlantic side of the continents of America the range is bounded by the parallels of 22° S. and 34° N.[38]

Such are the conditions which illustrate an oceanic phase of the far-reaching interrelations of nature and show how pelagic circulation is the beginning of a system which so fundamentally affects both the dispersal

[37] J. T. Nichols and R. C. Murphy: On a Collection of Marine Fishes from Peru, *Bull. Amer. Museum of Nat. Hist.*, Vol. 22, 1922, pp. 501–516.

[38] The northernmost coral reef in the world lies off Beaufort, N. C.

and the limitation of marine life. It is not the writer's purpose to discuss here the moot subject of the effect of the Humboldt Current upon the distribution of terrestrial organisms along the Pacific coast of South America. Ashore, on the seaward slope of the Andes, we encounter complex climatic factors wherein the relative weight which should be given to oceanographic influences and to circumstances of purely continental meteorology, in the interpretation of such terrestrial distribution, is still open to question. Whatever a study of the facts may yield, it is significant that a very large number of land animals parallel the marine life of the Humboldt Current, inasmuch as they extend their ranges northward toward the equator in the narrow strip of coastal desert which faces from the mountains toward the Pacific.[39]

[39] Cf. F. M. Chapman: The Distribution of the Swallows of the Genus *Pygochelidon*, *Amer. Museum Novitates No. 30*, 1922 (especially pp. 11–15, with distributional maps).