CONCERNING THE GEOGRAPHIC DISTRIBUTION OF THE YELLOW FEVER MOSQUITO.

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INTRODUCTORY NOTE TO REVISED EDITION.

The paper which follows is practically identical with the one published as a supplement to the Public Health Reports, Volume XVIII, No. 46, November 13, 1903, with the exception of the addition of a large number of definite localities in which *Stegomyia fasciata* has since been discovered. No especial effort has been made to collect this mosquito along the coast or in low-lying regions well within the lower austral life zone, since it can with perfect safety be taken for granted that wherever in these regions there is an opportunity for the species to breed it will be found, or, if not, will establish itself with perfect ease when once introduced. During the summer of 1904, however, an especial effort was made to determine the occurrence of the species along the northern line of its distribution, and two assistants were sent during that period to make a thorough search for the species in the vicinity of the line of meeting of the upper and lower austral life zones. One of them, Mr. Herbert Barber, started in June in Texas, and carried his search as far as Lexington, Ky., whence he returned to Washington about the 1st of August. The other, Mr. T. H. Coffin, starting at Knoxville, Tenn., early in September, reached Washington in October.

There is no reason to alter in any respect the general conclusions reached in the paper as originally published, but a point must be brought out which is of considerable importance from a practical standpoint; that is that during the later summer months and in September and even early October yellow fever mosquitoes are brought northward beyond the limits of the lower austral life zone in railway trains, and particularly upon boats going up the Mississippi and Ohio rivers. In this way the mosquito is carried north of its permanent breeding regions, and while the extreme heat lasts it may breed for a

generation or two or even more at a point north of the limit of its permanent establishment. Thus, during September, 1904, another assistant, Mr. A. Busck, found *Stegomyia fasciata* breeding on the exposition grounds at St. Louis and also at another point 2 miles west of that city. The autumnal occurrences of the species at such railroad or river centers as Knoxville, Nashville, Chattanooga, and Louisville are to be explained in this way. The occurrence of Stegomyia on the docks at Baltimore was of a similar character, and the early last century outbreaks of yellow fever at northern seaports are of course to be explained on the ground of the introduction of the disease and the mosquito by means of sailing vessels from the Antilles. Such late summer extralimital and accidental generations are an undoubted source of danger in the case of an introduced and unprotected yellow fever patient, but they are accidental, are not constant, and are not perpetuated.

This danger is further diminished by the comparatively early appearance of frost in these northern limits.

The proper consideration of this now all-important species must necessarily be divided into two sections; first, the actual present distribution of the species so far as it can be ascertained; second, the exact limitations of the regions in which, if accidentally introduced, it may reasonably be expected to propagate and to become perfectly established. For immediate quarantine purposes the first of these is the most important, but, looking to the future, an exact knowledge of the regions which must be included in the second category is obviously scarcely less important.

1. The present known distribution of the species.

When Mr. F. V. Theobald published his two volumes, A Monograph of the Culicidæ of the World, in 1901, he stated roughly that *Stegomyia fasciata*, which at that time was not known to him as the "yellow fever" mosquito, ranged from 38° south latitude to 38° north latitude, and his map upon page 292, Volume I, indicated a general distribution throughout eastern Australia, western Sumatra, all of Java and Farther India, southern Japan, eastern Hindostan, the Seychelles, southeastern Africa, the African west coast, including Senegambia and the District Lagos, all of Spain, southern Italy, the east coast of South America from British Guiana to Rio de la Plata, all of Cuba, Jamaica, Haiti, and all of the southern United States. In Volume III of this important monograph, published in 1903, the same author includes the following under "New localities:" St. Kitts, Nevis, Antigua, Carriacou (Grenadine Islands), Trinidad (Hewlett), Barbados, Dominica, Montserrat (Low), Luzon, Philippine Islands (September 7, 1901, Miss C. S. Ludlow); Port Darwin,

South Australia; Para (Durham); Gambia (Burdett), taken in houses, McCarthy Islands, in July; Victoria, Seychelles (Denman); Nigeria (Hanley); Fiji (Hewlett). Elsewhere he adds: Tyre and Sidon, Palestine; old Calabar; Mashonaland; Malay Peninsula and eastern Archipelago; Argentina, South America.

In my book on mosquitoes, published in 1901, I gave the then known distribution in the United States, as follows:

> In the United States it is common in most of our Southern States. I have seen specimens from New Orleans, La.; Natchitoches, La.; and Napoleonville, La.; eastern Texas; Hot Springs, Ark.; Pelham, Ga.; Virginia Beach, Va.

Since that time many new localities have been discovered, and our present knowledge of the exact localities may be tabulated as follows (those from without the United States being our own records additional to those of Theobald):

UNITED STATES.—*Virginia:* Virginia Beach, Norfolk, Lynchburg, Danville, Richmond. *Kentucky:* Lexington, Middlesboro, Louisville, Richmond. *Illinois:* Cairo. *Tennessee:* Nashville, Knoxville, Clarksville, Chattanooga, Memphis, Columbia, Decherd, Athens, Bristol. *Arkansas:* Hot Springs, Helena. *Louisiana:* Ruddock, New Orleans, Baton Rouge, Napoleonville, Covington, Hammond, Shreveport, Franklin, Morgan City, New Iberia, Patterson. *Mississippi:* Pass Christian, Summit, Quarantine Station, Vicksburg, Clarksdale, Tutwiler, Belzoni, Holly Springs, Jackson, Winona, West Point, Tupelo, Corinth, Agricultural College, Biloxi. *Alabama:* Mobile, Decatur, Auburn, Tuscumbia, Huntsville, Yazoo City. *Georgia:* Atlanta, Pelham, Augusta, Savannah, Brunswick. *Florida:* Barrancas, Key West. *Texas:* Galveston, Houston, Victoria, San Diego, Tyler, Laredo, Austin, San Antonio, Corsicana, Brownsville, Alice, Colorado, Dallas, Paris, Edna, Fort Bliss (El Paso), Fort Ringgold (Rio Grande-Ludlow), *South Carolina:* Charleston, Columbia, Fort Fremont, Sullivans Island. *Arizona:* Nogales. *Maryland:* Baltimore (Carter)—breeding in fresh water on fruit wharf. *North Carolina:* Beaufort, Winston, Raleigh, Greensboro, Charlotte, Salisbury. *Indiana:* Jeffersonville. *Missouri:* St. Louis.

MEXICO.—Tampico, Acapulco, Guanajuato, Frontera, Vera Cruz, La Paz (Lower California), Coatzocoalcos, Pachuca, Tuxpan, Nautla, Tlacotalpam, Mazatlan, San Blas, Carmen, Cozumel, Champoton, Perihuete, Las Penas, Tepic, Pochutla, Progreso, Monterey, Cordoba, Orizaba, Salina Cruz, Saltillo, Ciudad Victoria, Linares, Merida, Tonala, Rincon Antonio.

They have been received from *British Honduras:* Belize, Ceiba, Puerto Cortez. *Nicaragua:* Bluefields. *Costa Rica:* Limon and Bocas del Toro, and have also been received from one of the low-lying localities not specifically designated. *Guatemala:* Livingston, Puerto Barrios.

From the *Hawaiian Islands* they have been received from Honolulu and Hilo.

They were collected by my assistant, Mr. Marlatt, in *Java* at Batavia, Soekaboemi, Garoet, and at Singapore, *Malay Peninsula.*

From the *Philippine Islands* they have been received from Iligan, *Mindanao;* Iloilo, *Panay;* from Manilla, Santa Cruz, Haganoy, and Bulacan, *Luzon*, and from Cebu.

In *Cuba* they have been received from Columbia Barracks, Habana; from Guantanamo, Daiquiri, Baracoa, San Antonio de los Banos, Cayamas, " Yaquaramoa," Santiago, Caimanera, Batabano, Santiago de los Vegas, Quemados, and the Isle of Pines.

From the British West Indies they have been received from Jamaica and Montserrat.

BAHAMA ISLANDS.—Nassau, Spanish Wells, Harbor Island, Current, Tarpon Bay, San Salvador, Long Island, and Government Harbor.

PANAMA.—Panama, Colon, Culebra, Ancon.

PORTO RICO.—Colon, Aguadilla, Sabana Grande, Ponce, Lares, San Juan, Mayaguez, Culebra, Henry Barracks, Cayey (Ludlow).

BRAZIL.—Campinas, Bahia, Rio de Janeiro, Sao Paulo, Para.

ECUADOR.—Guayaquil.

PERU.—Callao.

CHILE.—Valparaiso (Ludlow).

SAMOA.—Apia.

No European specimens have been received, but a very interesting locality has turned up in Ismailia, Egypt, whence specimens were received from Dr. W. C. Gorgas, of the United States Army. In a report on the mosquitoes of Egypt, the Sudan, and Abyssinia, published in 1904, Theobald records *Stegomyia fasciata* from Ismailia, Port Said, Khartoum, Pibor, Cairo, and on Nile steamers.

In regard to the Philippines, I am informed by Miss Clara S. Ludlow, of the Army Medical Museum, that in connection with the study of mosquitoes by the Medical Corps of the Army she has received *Stegomyia fasciata* from practically every post in the islands, occupied by the Army. As a matter of fact, most of these posts are, or were, near the sea or river valleys.

From the above it will be seen that although the actual localities which may specifically be designated from the United States are comparatively small in number, and that, although combining Theobald's list with our own, the actual localities from other parts of the world are also comparatively small, we have still sufficient facts to enable, in my opinion, a sound generalization, both as to probable actual occurrence and as to regions in which the species will readily establish itself if once introduced. It will be noticed that all of the occurrences within the United States, except a very few, fall within

the limits of what are known as the tropical and lower austral zones. These life zones include practically all of the southern United States which border on the Atlantic Ocean and the Gulf of Mexico, with the exception of those portions of Virginia, North and South Carolina, Georgia, and Alabama, which constitute practically the foothills of the Appalachian chain; in other words, western Virginia and North Carolina, the extreme northwestern corner of South Carolina, the northern part of Georgia, and the extreme northeastern corner of Alabama. Further than this, the lower austral zone includes the western half of Tennessee, the western corner of Kentucky, the extreme southern tip of Illinois, the southeastern corner of Missouri, and all of Arkansas except the northern portion. It also includes the southern portion of Indian Territory, southern Arizona, and some of northern Arizona, and southern strips in Utah, Nevada, and California.

In the greater part of the territory thus indicated, and *where the climate is not too dry*, *Stegomyia fasciata* will, with little doubt, upon close search, be found.

2. *The exact limitations of the regions in which, if accidentally introduced, it may reasonably be expected to propagate and to become perfectly established.*

All the rest of the lower austral territory just indicated, and *where the climate is not too dry*, will constitute a region where the yellow-fever mosquito if once introduced will undoubtedly flourish. Even in the drier portions of western Texas, southern New Mexico, southern Arizona, southern California, and southern Nevada, where the climate is exceptionally dry, there is a possibility that this species if once introduced will breed in the water supply of ranches, except possibly where the water is impregnated with alkali.

Having made this generalization for the United States, where through the admirable work of Dr. C. Hart Merriam and his Division of Biological Survey of the United States Department of Agriculture, the subject of the exact limitations of the life zones has been so accurately investigated, and where these zones have been so carefully mapped out, we naturally may follow it with a corresponding generalization for other countries where the factors which control the distribution of animal and vegetable life are, of course, comparable to those which exist in the United States. We may expect to find this species everywhere in the moist tropical zone, or at all events, when introduced at any point within the low, moist Tropics, it may be expected to establish itself. The conditions which control the distribution of life in the so-called lower austral zone will naturally hold equally in corresponding sections elsewhere, and it becomes necessary

to formulate as easy a means as possible of ascertaining a region between the parallels of latitude of 38° north and 38° south whose conditions will correspond to those of the lower austral zone in the United States and which will thus admit of the breeding of *Stegomyia fasciata.* It has been determined by Doctor Merriam that the northern limit of the lower austral zone is marked by the isotherm showing a sum of normal positive temperatures of 10,000° C., or 18,000° F. The sum of normal positive temperatures means the sum of normal mean daily temperatures above 6° C., or 43° F. With this rule as a basis we may take, for example, on the borders of the plateau region in Mexico, any given locality or elevation, and may sum up the normal mean daily temperatures above 6° C., or 43° F., and if this sum for the year reaches 10,000° C., or 18,000° F., it is safe to say that the locality is within the limits of the lower austral life zone and that the yellow-fever mosquito will breed there.

The minimum temperature of 6° C., or 43° F., has been estimated as marking the inception of reproductive activity in animals; in other words, the formula which we have just given means that the physiological constant of *Stegomyia fasciata* is approximately 10,000° C. I have, in the opening paragraph under this head, italicized the clause "where the climate is not too dry," for while, as shown by Merriam, the temperature predetermines the possibilities of distribution and fixes the limits beyond which the species can not pass, and defines certain broad transcontinental belts within which certain forms may thrive, *if other conditions permit*, it is by no means the sole factor which determines distribution. Nevertheless, no matter how favorable other conditions may be the species possessing the physiological constant characteristic of this zone can not exist outside. With mosquitoes it is obvious that the factor next in importance to temperature will be moisture, and in the arid Tropics and in the very dry portions of the lower austral zone we will naturally not look for an abundance of mosquitoes, except under artificial conditions brought about by civilization. *Stegomyia fasciata*, however, being a domestic species—that is to say, being practically dependent upon the conditions surrounding human habitations—is less subject to normal conditions of moisture than are the species of the fields and woods.

It is interesting to note that the geographic distribution of the yellow-fever mosquito corresponds rather well with that of the Texas cattle tick (*Boöphilus annulatus*) which is instrumental in the carriage of the Hæmatozoan of Texas fever. That, too, is a creature which seems confined to the tropical and lower austral zones.

The southern border of the lower austral zone has not been expressed in a similar formula, but this is unnecessary for the present consideration, since the mosquito breeds readily in both tropical and lower austral zones.

The southern limit of the zone in the Southern Hemisphere, corresponding to the northern limits of the lower austral life zone in the Northern Hemisphere, can probably be calculated by the use of the same formula, and thus in any given locality in the Southern Hemisphere the probable occurrence, or at all events the proper climatic conditions for the existence of *Stegomyia fasciata*, can be ascertained.

I conceive that the facts thus formulated are and will be of great importance in the determination of quarantine measures, and that the careful records which have been urged by the international congress of sanitarians of the American Republics will justify these broad conclusions.

In an article published in the Journal of Tropical Medicine, for August 1, 1903, Mr. Theobald gives some further notes concerning the distribution of other species of *Stegomyia*, in which he shows a slightly greater northern and southern distribution with other forms of the same genus, enlarging the field to from 43° south to 43° north latitude. As yet, however, the agency of only a single species, *Stegomyia fasciata*, in the transfer of yellow fever, has been proved. Let us for the present await experimentation with the other species, of which there are nearly a score, before beginning further attempts at generalizations. In fact, it may very likely be shown that these species have not so close a relationship to *S. fasciata* as to warrant the belief that they may be instrumental in the carriage of this disease. In fact the Australian species, *Stegomyia notoscripta*, laying its eggs, as it does, in "rafts," and not singly, as does *S. fasciata*, may very likely prove to be a distant rather than a close relative of the dangerous form.

Since this statement was published in the first edition of this paper, Mr. Theobald has established a new genus for *Stegomyia notoscripta*, and it is probable that the other extralimital forms will be removed from Stegomyia.

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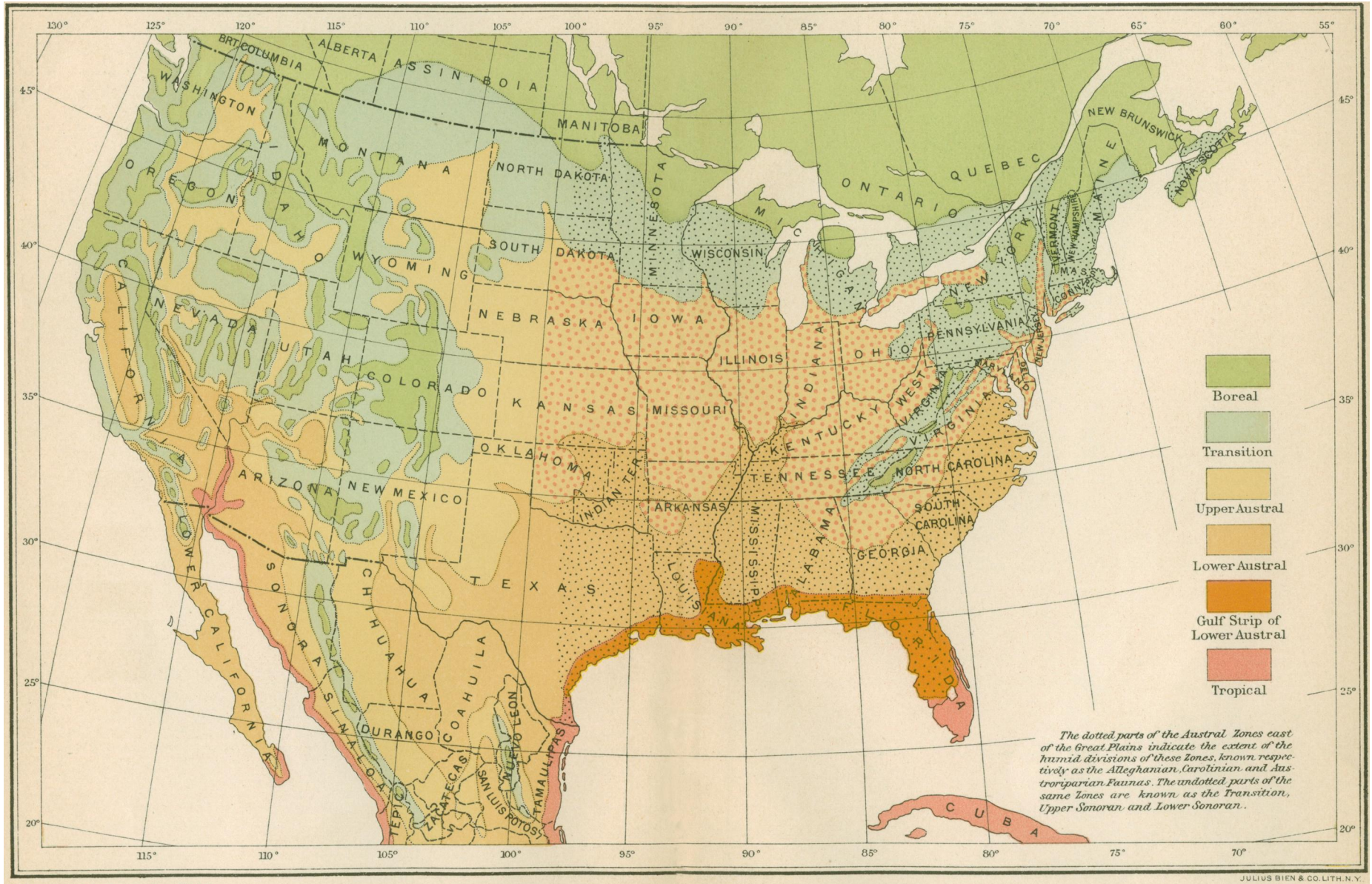

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LIFE ZONES OF THE UNITED STATES

BY

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