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THE SPREAD OF TICK-BORNE BORRELIOSIS IN WEST AFRICA AND ITS RELATIONSHIP TO SUB-SAHARAN DROUGHT

JEAN-FRANCOIS TRAPE, BRUNO GODELUCK, GEORGES DIATTA, CHRISTOPHE ROGIER, FABRICE LEGROS, JEAN ALBERGEL, YANNICK PEPIN, AND JEAN-MARC DUPLANTIER

Laboratoire de Paludologie, Service d'Hydrologie, et Programme Eau et Sante, Institut Francais de Recherche Scientifique pour le Developpement en Cooperation (ORSTOM), Dakar, Senegal; Service d'Epidemiologie, Institut Pasteur, Dakar, Senegal

Abstract. In West Africa, tick-borne relapsing fever is due to the spirochete *Borrelia crocidurae* and its geographic distribution is classically limited to the Sahel and Saharan regions where the vector tick *Alectorobius sonrai* is distributed. We report results of epidemiologic investigations carried out in the Sudan savanna of Senegal where the existence of the disease was unknown. A two-year prospective investigation of a rural community indicated that 10% of the study population developed an infection during the study period. Transmission patterns of *B. crocidurae* to humans and the small wild mammals who act as reservoirs for infection were similar to those previously described in the Sahel region. Examination of 1,197 burrows and blood samples from 2,531 small mammals indicated a considerable spread of the known areas of distribution of *A. sonrai* and *B. crocidurae*. The actual spread of the vector and the disease has affected those regions where the average rainfall, before the start of the extended drought in West Africa, reached up to 1,000 mm and corresponds to the movement of the 750-mm isohyet toward the south from 1970 to 1992. Our findings suggest that the persistence of sub-Saharan drought, allowing the vector to colonize new areas in the Sudan savanna of West Africa, is probably responsible for a considerable spread of tick-borne borreliosis in this part of Africa.

Infection by the spirochete *Borrelia crocidurae* causes an acute febrile illness in humans. Untreated patients experience relapses of illness that are characteristic of the disease and severe meningoencephalitic complications can ensue.[1–3] Small wild mammals act as a reservoir for *B. crocidurae*.[4–6] Humans are infected when bitten by the ornithodorean tick *Alectorobius* (*Theriodoros*) *sonrai* (Sautet and Witkowski, 1944),[7,8] the only known vector, which lives in burrows, but can occasionally bite outside the burrows.[5,9] Until recently,[10] this borreliosis was considered a rare disease, the geographic distribution of which was limited in West Africa to the Sahel and Saharan regions, from Mauritania and northern Senegal to Chad.[5,10–12] The southernmost locality where *A. sonrai* has been collected in West Africa was Gandigal, Senegal (14°28′N, 16°59′W).[11] Most of the areas where the presence of *A. sonrai* has been recorded are situated in regions where the average rainfall before 1970 was less than 500 mm and none reached the 750 mm isohyet, which was considered the southern limit of the vector's distribution.[11]

Several cases of borreliosis that we have diagnosed in Senegal during a survey carried out in 1989 and 1990 concerned patients living south of the 14th parallel, where the existence of the disease had, until then, been unknown.[10] This led us to undertake a series of epidemiologic investigations whose aim was to address two questions that arose from these observations: 1) does local transmission of tick-borne borreliosis really occur in the Sudan savanna of West Africa, and, if so, with which epidemiologic features?; and 2) if a spread of this formerly Saharo-Sahelian disease is established, is it related to the climatic changes that have affected West Africa since the start of the 1970s?

MATERIALS AND METHODS

To assess the incidence of the disease and to define its modes of transmission, a prospective study was done over a two-year period among the population of a village of southwestern Senegal (Dielmo; 13°45′N, 16°25′W) that had previously been selected for a malaria research project.[13] The climate and vegetation are typically Sudanian in this area where annual rainfall averaged 1,000 mm before 1970. A detailed description of the study population and the protocols of medical and epidemiologic surveillance are given elsewhere.[13] Briefly, from June 1990 to May 1992, the villagers were visited at home six days a week for clinical and epidemiologic monitoring. The dispensary built in the village for the project remained open 24 hr a day to rapidly identify and treat all episodes of illness. A thick blood film was taken in all cases of fever, stained with Giemsa, and 200 oil-immersion fields (× 1,000) were systematically examined for *B. crocidurae* (equivalent to approximately 0.5 μl of blood).

Small mammals were trapped alive with lattice-work traps, baited with peanut butter or onions, in Dielmo and 35 other rural areas in Senegal between September 1989 and June 1993. Two methods of detection of *B. crocidurae* were used.[14] The captured animals were killed with chloroform and blood samples were taken by intracardiac tapping. Using this blood, a thick blood film was made and stained with Giemsa for direct examination for *B. crocidurae*, and two white mice were given intraperitoneal injections of approximately 0.3 ml each. Six days after inoculation, thick blood films were prepared from the mice and examined for *B. crocidurae*.

Tick surveys were made between November 1990 and December 1993 in 10 regions situated south of the 14th parallel where the existence of *A. sonrai* was unknown and three regions between 14°30′N and 15°30′N, which were considered at the southern limit of the vector. Rodent burrows opening in houses (traditional mud huts) and in nearby fields were examined for *A. sonrai* by introducing a flexible tube inside burrows and aspirating their contents using a portable, petrol-powered aspirator. A total of 70 rodent burrows were examined before a given study area was considered to be negative.

Data from 66 rain gauge stations were used to draw the isohyets charts of Senegal using the Kriging geostatistical method[15,16] for 23-year periods (1947–1969 and 1970–1992), i.e., before and after the begining of sub-Saharan drought.[17,18] Kriging is a method for estimating variables distributed in space by linear interpolation of observations, minimizing the variance of estimations.[15,16]

RESULTS

Epidemiologic studies in Dielmo. Of the 247 villagers enrolled in the study on June 1, 1990, 180 were constantly surveyed for two years. Sixty-seven persons left the study before the May 31, 1992 and 57 additional persons (migrants and newborn babies) were enrolled. The mean study population was 235 people.

A total of 24 cases of borreliosis were diagnosed during that period, for an average annual incidence rate of 5.1%. Cases appeared sporadically throughout the duration of the study, in the dry as well as the rainy season. The age of the patients ranged from 15 months to 52 years and no significant difference in the rate of incidence was observed in relation to age group. The daily recording of every villager's traveling was conclusive in precisely locating the place of infection for most patients. Twenty of those infected had spent every night at home the month preceding the start of clinical symptoms and had not left the immediate surroundings of the village. For two patients, infection had taken place either in the village or in another village within a 10-km radius. For one person diagnosed on returning from an extensive trip in the Dakar region, we were able to rule out local infection. In the case of one patient who traveled frequently, the place of infection was unknown.

The evidence for local transmission led us to investigate the reservoir of the disease and its vector. A total of 275 rodents and insectivores belonging to eight species were collected during 1,830 trap-nights of capture in houses and nearby fields. Of these animals, 251 were tested for *B. crocidurae* by direct examination of thick blood films and 232 (203 *Mastomys erythroleucus*, 19 *Arvicanthis niloticus*, four *Cricetomys gambianus*, three *Tatera gambiana*, one *Heliosciurus gambianus*, one *Rattus rattus*, and one *Crocidura* sp.) were also studied by intraperitoneal inoculation of their blood into a white mouse. Two animals (0.8%) were found infected by the direct method (one *M. erythroleucus* and one *Arvicanthis niloticus* and seven animals (3.0%) by the inoculation method (six *M. erythroleucus* and one *Arvicanthis niloticus*). Of the 342 burrows examined during four surveys between August 1991 and July 1992 (272 inside houses and 70 in the fields), 28 (8.2%) contained *A. sonrai* (8.5% inside houses and 7.1% in the fields). Twelve batches of 10–15 *A. sonrai* collected inside houses were ground in saline solution and then inoculated intraperitoneally into white mice. Four of the batches produced *B. crocidurae* infection in white mice. In an additional experiment, a batch of *A. sonrai* was put onto an immobilized white mouse and five of the ticks became engorged. Ten days afterwards, *B. crocidurae* was observed in blood smears taken from the mouse. In six bedrooms of villagers who had recently suffered borreliosis, a sentinel white mouse was kept for one night in a cage that was put on the floor of the room near the bed, approximately 50 cm from the entrance of a burrow. Two of the six white mice developed an infection between six and 10 days later.

Further investigations in Senegal. Investigations in Dielmo suggested a spread of tick-borne borreliosis reaching the former 1,000-mm isohyet at latitude 13°45'N, i.e., nearly a degree of latitude further south than the formerly known southern limit of the vector's and disease's distribution in Senegal. Therefore, we decided to systematically investigate the presence of *A. sonrai* south of the 14th parallel (Figure 1). Ten of the regions of Senegal situated between 12°30'N and 13°59'N were studied, and the results were compared with those of three regions between 14°30'N and 15°30'N, regions that, until now, have been considered to be at the southern limit of the vector. Between 14°30'N and 15°30'N, of 278 burrows examined, 118 (42%) contained *A. sonrai*. The proportion of positive burrows in each of the three regions studied was 41%, 37% and 32%, respectively. Between 13°30'N and 13°59'N, of 465 burrows examined in five different regions (Dielmo village and one region per degree of longitude between 12°W and 17°W), 35 (7.5%) contained the vector. At this latitude from the Atlantic Ocean on the west to the border with Mali on the east, we constantly found *A. sonrai*. Between 12°30'N and 13°29'N, we found *A. sonrai* in one burrow (in Dar-Salam; 13°15'N, 13°12'W) of 454 studied in six different regions (one region per degree of longitude between 11°W and 17°W).

To establish whether borreliosis could be considered absent from the most southern regions of Senegal where we did not find the vector, between 12°30'N and 13°15'N, we tested for *B. crocidurae* by direct thick blood film examination a total of 367 rodents captured in 13 different locations (nine in southeastern Senegal and four in Casamance) and 927 patients with acute fever from a dispensary in Casamance (Mlomp, 12°33'N, 16°35'W). A sample of 43 rodents including 30 *Mastomys erythroleucus*, nine *Myomis daltoni*, and four *Rattus rattus* was also studied by the inoculation method. No cases of infection were observed. In contrast, between 13°30'N and 14°N, we documented cases of infection in humans and/or rodents in each degree of longitude from 12°W to 17°W. Of 2,164 rodents and insectivores belonging to 14 species captured in 23 locations between 13°30'N and 16°30'N, 195 (9.0%) were found infected by direct thick blood film examination (Table 1). This concordance was also found for the origins of infection of 126 patients who we studied between 1989 and 1993. With the possible exception of one case (a patient who traveled in different localities of southeastern Senegal), all of the patients were infected to the north of 13°30'N latitude.

Relationship to rainfall. Since the 750-mm isohyet has previously coincided with the known southerly limit of the vector,[11] the drought in sub-Saharan Africa, persistent since 1970, might explain the vector's progression and the spread of the disease towards the south. To test this hypothesis, we mapped the average annual precipitations in Senegal for the periods 1947–1969 and 1970–1992, and studied the relationship between rain gauge readings between these two periods of time and the present known distribution of the vector.

Figure 1 shows that between 13°30'N and 13°59'N, the latitudes where we constantly found *A. sonrai*, the average rain gauge readings have decreased by approximately 25% since the beginning of the drought period. While the average

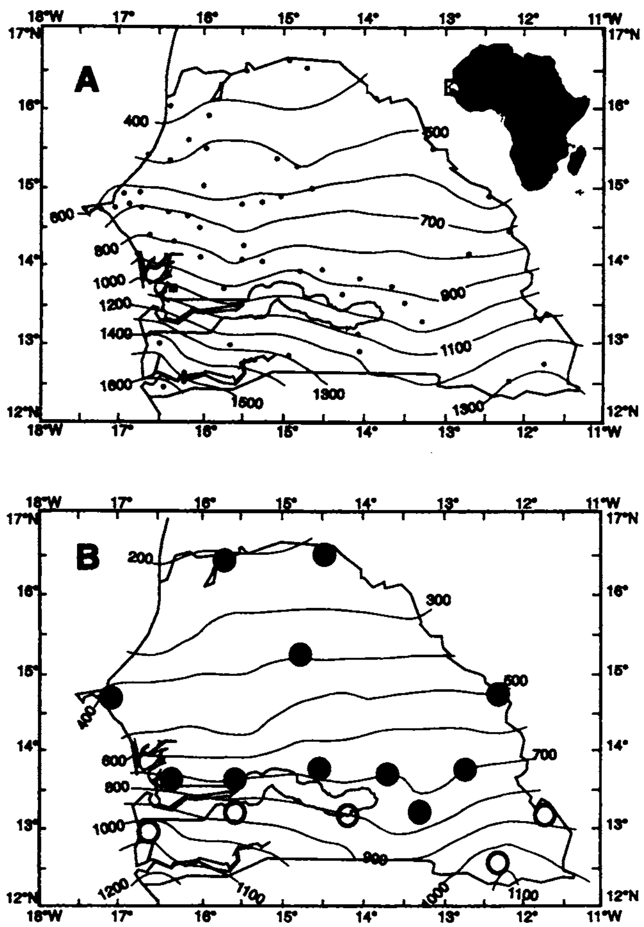

FIGURE 1. Climatic changes and geographic distribution of the vector tick *Alectorobius sonrai* in Senegal. **A,** isohyet map of Senegal for the period 1947–1969, i.e., before the begining of sub-Saharan drought, with localization of the 66 rain gauge stations used to draw the isohyets charts **(black points)** and Dielmo village **(black square)**. **B,** isohyet map of Senegal for the period 1970–1992 and present distribution of *A. sonrai.* The areas studied where we observed the presence of *A. sonrai* are shown as black dots and those where our investigations failed to demonstrate the presence of this tick are shown as white dots. Rainfall values are in millimeters.

rainfall varied, according to the regions, from 850 mm to 1,000 mm for the period 1947–1969, it was always less than 750 mm for the period 1970–1992. Between 12°30'N and 13°30'N, the average rain gauge readings decreased in similar proportions, but remained greater than 800 mm in each of the regions in which our studies were unable to demonstrate the presence of either *A. sonrai* or *B. crocidurae.* In the case of the only area in which we found the vector, rain gauge readings of the station nearest to the collection locality of *A. sonrai* (Dialakoto, 10 km northeast of Dar-Salam) indicated an average of 749 mm for the period 1970–1992.

DISCUSSION

Tick-borne borreliosis is endemic in all regions of Senegal north of latitude 13°30'N, and at least 11 species of small mammals act as reservoirs for the infection. Nine different species were found infected in this study. Except for *Mastomys huberti* and *Taterillus gracilis,* all were previously known reservoirs of *B. crocidurae* in Senegal.[4,19] Two other species (*Rattus norvegicus* and *Atelerix albiventris*) have been found infected in Senegal by a previous investigator.[4]

Investigations in Dielmo show for the first time that tick-borne borreliosis is locally transmitted in a Sudan savanna area of West Africa, with epidemiologic features similar to those previously described in the Sahel.[9–11,20] The incidence of the disease appears to be very high since 10% of the study population developed an infection over a two-year period. In a previous study, we showed that relapsing fever was also a common cause of morbidity in the Sahelian villages of westcentral Senegal, where this disease represented from 1.6% to 4.2% of the causes of fever in older children.[10]

Our findings indicate a considerable range extension for *B. crocidurae* and its vector *A. sonrai.* The southernmost location where the vector has been collected reaches 13°15'N, i.e., more than one degree of latitude further south than its formerly known limit.[11] It is possible that tick-borne borreliosis has until now been ignored in the Sudan savanna regions of West Africa because of the frequent low density of *B. crocidurae* in patients blood.[10] Although it is clear that most cases remain undiagnosed even in areas where the disease is known to occur, we believe that this hypothesis is improbable for a disease whose clinical features are so characteristic in the absence of specific treatment, and whose annual incidence within the general population may reach 5%. Furthermore, to our knowledge all cases among tourists in West Africa that are documented in the literature concerned patients who traveled in Sahelian countries, and no case of human or animal infection whose precise origin is known has been recorded outside of these regions. In particular, we were unable to find data supporting the idea of the presence of either *A. sonrai* or endemic tick-borne relapsing fever in Guinea Bissau, Cote d'Ivoire, or Togo, despite the mention of these countries on a World Health Organization distribution map of endemic tick-borne relapsing fever in Africa.[21] This document was based on a former map using health statistics of the period 1946–1954 as sources for the occurrence of relapsing fever in these countries.[22] During that period, which followed World War II and the return to their country of African soldiers, local epidemics of louse-borne relapsing fever due to *B. recurrentis* occurred in many localities of West Africa,[22,23] and this spirochete was probably responsible for most cases attributed to *B. crocidurae.* Furthermore, places of contamination of patients with presumed *B. crocidurae* infections were not systematically investigated to exclude travelers from Sahelian regions of West Africa. Finally, *A. sonrai* was not found in the Sudan savanna of Senegal, although this area has been intensively investigated for *A. sonrai* and other ticks since the early 1960s as part of research programs on arboviruses.[24–26]

We believe that the most probable explanation for our observations is that the spread of the endemic area has occurred recently. Global warming and its associated climatic changes are expected to affect a wide range of ecologic processes, with consequences on vector-borne diseases transmission.[27–29] Since *A. sonrai* is an endophilic tick that lives in burrows in semiarid and sahelian regions, specific ranges of humidity and temperature in the ground are probably major determinants of its distribution.[5,11] Our findings support the hypothesis that the persistence of sub-Saharan drought

TABLE 1

List of species of small mammals investigated and results of direct thick blood film examinations according to the latitude of the study area*

Species	12°30'–13°15'N N	12°30'–13°15'N P	13°30'–14°N N	13°30'–14°N P	14°30'–16°30'N N	14°30'–16°30'N P	Total N	Total P
Rodents†								
Heliosciurus gambianus	0	0	1	0	0	0	1	0
Desmodilliscus braueri	0	0	0	0	10	0	10	0
Tatera gambiana	5	0	34	0	8	3	47	3
Taterillus gracilis (complex)	0	0	1	0	45	8	46	8
Cricetomys gambianus	0	0	4	0	17	3	21	3
Arvicanthis niloticus	0	0	19	1	767	107	786	108
Dasymys incomtus	0	0	0	0	4	0	4	0
Mastomys erythroleucus	161	0	238	2	248	24	647	26
Mastomys huberti	57	0	41	0	260	37	358	37
Mastomys natalensis	35	0	0	0	0	0	35	0
Mus musculus	0	0	0	0	320	5	320	5
Myomis daltoni	20	0	1	0	11	0	32	0
Rattus rattus	86	0	17	1	18	0	121	1
Insectivores								
Atelerix albiventris	0	0	0	0	15	0	15	0
Crocidura sp.	3	0	0	0	85	4	88	4
Total	367	0	356‡	4	1,808	191	2,531	195

* N = number tested; P = number positive.
† Nomenclature according to Duplantier and Granjon.[30]
‡ Dielmo (251 tests, two positive results) and four other locations.

is responsible for a large spread of tick-borne borreliosis in West Africa by allowing the vector tick *A. sonrai* to colonize new savanna areas. This would be the first known example of a vector-borne disease whose spread in West Africa has been caused by present climatic changes.

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Authors' addresses: Jean-Francois Trape, Bruno Godeluck, Georges Diatta, and Fabrice Legros, Laboratoire de Paludologie, ORSTOM, BP 1396, Dakar, Senegal. Christophe Rogier, Service d'Epidemiologie, Institut Pasteur, BP 220, Dakar, Senegal. Jean Albergel and Yannick Pepin, Service d'Hydrologie, ORSTOM, BP 1386, Dakar, Senegal. Jean-Marc Duplantier, Programme Eau et Sante, ORSTOM, BP 1386, Dakar, Senegal.

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