Medical and Veterinary Entomology (2000) **14**, 19–30

Distribution of domestic Triatominae and stratification of Chagas Disease transmission in Oaxaca, Mexico

J. M. RAMSEY, R. ORDOÑEZ, A. CRUZ-CELIS, A. L. ALVEAR, V. CHAVEZ, R. LOPEZ, J. R. PINTOR*, F. GAMA* and S. CARRILLO*

Centro de Investigaciones sobre Enfermedades Infecciosas (CISEI), Instituto Nacional de Salud Publica (INSP), Cuernavaca, Morelos, Mexico and *Servicios de Salud del Estado de Oaxaca, Mexico

Abstract. Mexico has 18 species of Triatomine bugs (Hemiptera: Reduviidae) reported to be vectors of *Trypanosoma cruzi*. Chagas Disease is widespread in Mexico, with up to 3.5% seropositivity of human transfusion blood. The State of Oaxaca has the longest history of endemic Chagas Disease, based on acute and chronic case reports, and of entomological surveys in the country. However, the State health care services need more information on current risks of vector transmission. In order to identify and characterize areas of transmission in Oaxaca and to stratify the vector potential, the distribution of domestic Triatominae was surveyed during 1996–98 in collaboration with the primary health care services and local communities. Villages were studied in 11% of 570 municipalities in Oaxaca. Eight triatomine species were found in domestic and peri-domestic habitats: *Triatoma barberi* Usinger, *T. bolivari* Carcavallo *et al.*, *T. dimidiata* (Latreille), *T. mazzottii* Usinger, *T. nitida* Usinger, *T. pallidipennis* (Stal), *T. phyllosoma* (Burmeister) and *Rhodnius prolixus* Stal. For each triatomine species in Oaxaca, the range of distribution and habitat characteristics are described. Habitat partitioning, principally based on altitude and mean annual precipitation, limited the overlap of distribution between species. Relatively consistent altitude of human settlements facilitates the dispersion of individual species within microregions. Entomological indices of house infestation were used to estimate that ~50% of the human population (1874 320 inhabitants) would be at risk of vector transmission, with a minimum of 134 320 infected people and 40 280 chronic cases of Chagas Disease currently in Oaxaca.

Key words. *Rhodnius prolixus, Triatoma barberi, T. dimidiata, T. mazzottii*, altitude, Chagas Disease vectors, demography, domestic infestations, habitat partitioning, PHC system, rainfall, stratification, Oaxaca, Mexico.

Introduction

Chagas Disease is given little public health priority in Mexico, despite ample clinical and experimental evidence of its importance and estimates exceeding 44 000 new cases per annum (Tay, 1980; Salazar Schettino *et al.*, 1988; Schmunis, 1996). The Secretary of Health reports an average infection prevalence in blood donors of 1.49%, rising to 16.5% in some samples, but does not report clinical cases (PAHO, 1997). The causative agent of Chagas Disease, *Trypanosoma cruzi* (Chagas) (Kinetoplastida: Trypanosomatidae), is normally transmitted biologically via blood-sucking triatomine bugs (Hemiptera: Reduviidae), or directly by passage of infected blood. Twenty-seven species of Triatominae have been recorded from Mexico, of which 23 are unknown from other countries (Zarate & Zarate, 1985). Kinetoplastid flagellates, putatively *T. cruzi* in most cases, have been reported from at least 18 species of Triatominae in Mexico.

Correspondence: Dr Janine Ramsey, Centro de Investigaciones sobre Enfermedades Infecciosas (CISEI), Instituto Nacional de Salud Publica, Av. Universidad 655, Cuernavaca, Morelos 62508, Mexico. E-mail: jramsey@INSP3.insp.mx

Within Mexico, the State of Oaxaca currently reports the highest *T. cruzi* seropositivity in blood donors (3.5%). Oaxaca is where the first cases of Chagas disease in Mexico were found in the late 1930s (Mazzotti, 1940a). The same team encountered four species of domestic Triatominae in Oaxaca during that period: *Triatoma barberi*, *T. phyllosoma* (short-winged), *T. mazzottii* (= *T. phyllosoma* long-winged of Mazzotti & Osorio, 1942) and *Rhodnius prolixus* (Brumpt *et al.*, 1939). Trypanosome-infected *T. dimidiata* were reported from Oaxaca by Mazzotti & Dias (1949). Subsequent studies reported the widespread distribution of domestic triatomines in Oaxaca: *T. barberi* from five localities (Dias, 1951; Little *et al.*, 1966; Brodie & Ryckman, 1967; Tay, 1969), *T. phyllosoma* from four localities (Dias, 1951; Martinez & Martin, 1981), *T. dimidiata* from three localties (Dias, 1951; Biagi & Navarrete, 1960; Goldsmith *et al.*, 1978), *T. mazzottii* from 14 localities (Dias, 1951; Biagi & Navarrete, 1960; Tay & Biagi, 1964; Little *et al.*, 1966; Tay, 1969) and *R. prolixus* from five localities (Santo Domingo Teojomulco-Mina del Carmen, San José de las Flores, Jamiltepec, Putla de Guerrero, Cerro del Aire) (Dias, 1951; Biagi & Navarrete, 1960; Goldsmith *et al.*, 1978). Reports of *T. picturata* are considered to be misidentifications of *T. phyllosoma*. Altogether there are published and unpublished reports of five species of Triatominae from 36 villages in Oaxaca State.

In order to stratify Chagas Disease transmission potential in Oaxaca, the current distribution of domestic Triatominae was surveyed during 1996–98 in collaboration with the primary health care services and local communities. The aims were: (1) to identify triatomine species found in domestic habitats and compare results with previous entomological surveys; (2) to seek possible correlations between vector presence and geographical variables; and (3) to attempt a geographical stratification of the risk of *T. cruzi* transmission to humans.

Materials and Methods

Study area

The State of Oaxaca (area 94 200 km^2) lies on the south-west Pacific coast of Mexico (Fig. 1), representing 4.8% of the country's total area and bordering on the states of Puebla, Veracruz, Chiapas and Guerrero. Topography ranges from sea level to 3880 m altitude, with multiple mountain ranges including the southern Sierra Madre, the Puebla volcanic range and the Chiapas-Central American Sierras. The central valley of Oaxaca is bordered by the Mixteca and Zapoteca Sierras, Isthmus of Tehuantepec, Veracruz lowlands, southern Sierra Madre and Pacific coastal plain. Climatically, most of Oaxaca is sub-humid to semi-dry, with mean annual temperature range of 6.6°C to 27.4°C, and mean annual precipitation of 730 mm. Only 12% of Oaxaca's land is considered appropriate for cultivation; 25% is used for livestock and 41% is covered with low deciduous or tropical forest.

The population of Oaxaca is 3 019 560 (INEGI, 1995), 42.6% under 15-years-old, and 60.5% live in rural communities of less than 2500 inhabitants/village. The State of

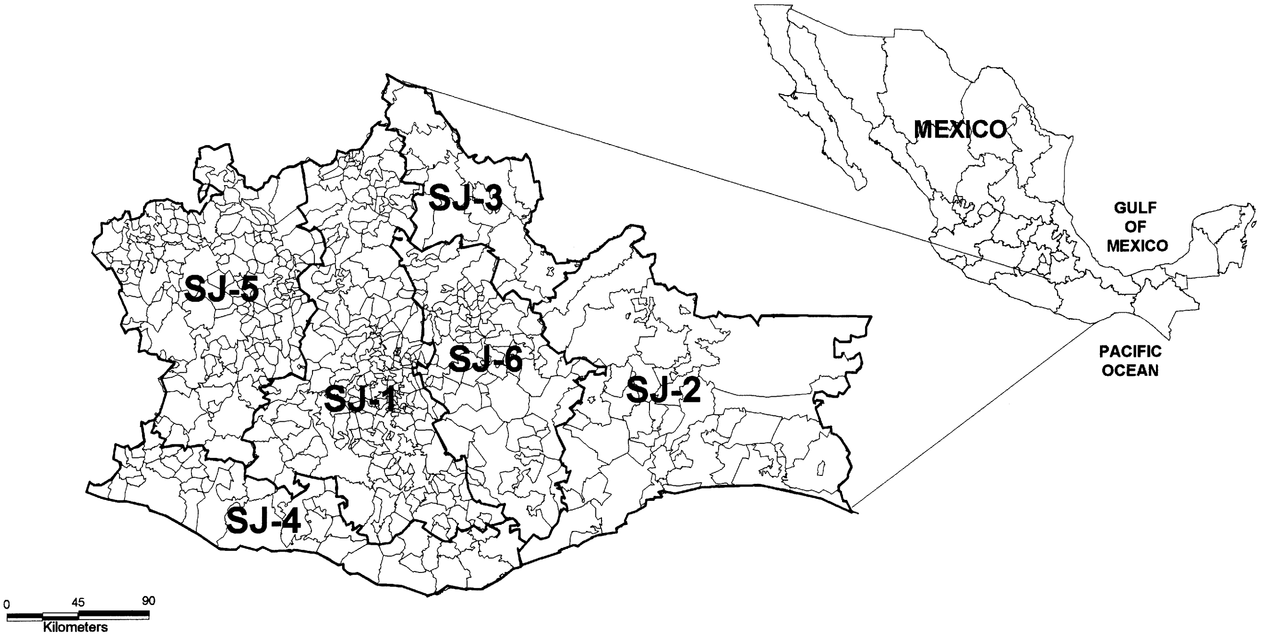

Fig. 1. Oaxaca State of Mexico, showing municipal (minor divisions) and primary health care service organization (SJ = Sanitary Jurisdiction).

Oaxaca still nurtures many cultural traditions: 33.7% of the population speak one of 16 distinct indigenous languages, while bilingual education with Spanish now extends to 40% of the indigenous population.

PHC system and entomology surveys

The primary health care (PHC) system in Oaxaca (Servicios de Salud del Estado de Oaxaca) is divided into six regional Sanitary Jurisdictions (SJ), which manage the 15 priority health programmes in 570 municipalities (Fig. 1). Although each conducts separate activities, they implement an integrated approach with health promotors, medical brigades and vector control personnel, who visit communities with established frequency. This network extends to marginalized villages with as few as 100 inhabitants. PHC activities were decentralized to the state level generally in 1997, and for Chagas Disease activities authorized by the National Vector Control Program in 1998. Two entomologists in the State of Oaxaca had received prior training on Triatominae and other aspects of medical entomology, but local PHC and vector control personnel had no formal experience of Chagas Disease or its transmission prior to this study.

Entomological surveys were conducted by general PHC personnel (in two SJs) or by vector control personnel (in four SJs). Certain areas of the Mixtecan Sierra and those bordering on Puebla and the Veracruz lowlands are under-represented in collections. After being given general information and orientation on Chagas Disease and its transmission, PHC workers enquired, during their routine visits to villages, about the presence of domestic bugs. To help communication with villagers, PHC visitors used life-size coloured photographs illustrating triatomine nymphs and adults of all previously recorded species. Residents were requested to collect bugs found in dwellings, and the PHC workers noted the date and site of collection (domestic, peridomestic or sylvatic), name of house-owner, house number, locality and municipality. Bug specimens from the SJs were sent to CISEI, Cuernavaca. Entomology personnel collaborated with SJ technicians in villages where bugs had been found by the community, to train them in timed search methods and, in some cases, the use and monitoring of collection traps (Gomez Nuñez, 1965).

Triatomine identification and T. cruzi *infectivity*

All bugs received were assigned an identification number for recording the following information in a database: type and date of collection, SJ number, municipality, village, name of person collecting bugs, number and stages of bugs collected, species, whether bugs were received live or dead, date of receipt, and any other information sent with the collection, such as type of housing construction. Live bugs were placed in breeding containers and maintained in an insectary at 30°C and 70% relative humidity. Within one week of receipt, a sample of bug faeces was collected and observed by microscopy for possible infection with *T. cruzi*. Salivary glands of representative insects were extracted and examined for possible infection with *T. rangeli*.

Data analysis

Infestation, colonization and crowding indexes were calculated according to WHO (1991), at the village level and, subsequently, for each species. Infestation indices are reported only for those species where trained personnel surveyed at least 5% of dwellings in a village. Census and geographical data were obtained in digitized format from the Instituto Nacional de Estadistica, Geografia e Informática (INEGI); for villages where triatomines were collected the databases were analysed and populations at risk estimated. The numbers of people infected and having chronic disease were calculated from known seroprevalence for specific regions (3.5% for blood donors in the Central Valleys; 13% for coastal *T. mazzottii*) or an estimated 6% for other rural areas. Assuming that 33% of the infected population will develop chronic disease symptoms (Schofield, 1991; Schmunis, 1996), the costs of diagnosis and treatment were calculated based on figures for Argentina (del Rey *et al.*, 1995) and the economic burden based on that calculated for the whole of Latin America (World Bank, 1993).

Results

Triatomine bugs were obtained from 98 villages distributed in 62 (11%) of the municipalities in Oaxaca State (Table 1). *Rhodnius prolixus* and seven species of *Triatoma* were collected from domestic habitats: *T. barberi* from 25 villages, *T. mazzottii* from 30 villages, *T. phyllosoma* from 24 villages, *T. dimidiata* from 13 villages, *T. pallidipennis* from four villages, *T. bolivari* from three villages, *T. nitida* from two villages and *R. prolixus* from two villages (Nejapa de Madero, San Martin de Porres). All except *T. nitida* and *R. prolixus* were also found in other habitats of the village environs. *Triatoma mazzottii* was collected from rock-piles in fields of corn and peanuts, associated with rodent nests (*Peromyscus mexicanum*); *T. phyllosoma* from rock-piles and cliff nests of small rodents; *T. pallidipennis* in association with bat caves, and *T. barberi* from corn fields associated with small rodents.

Triatomine mazzottii and *T. dimidiata* seem to have discontinuous distributions within Oaxaca State. Both species are present in domestic habitats near or bordering lowlands with high annual precipitation, along the Pacific coast or bordering on the State of Veracruz (Fig. 2). *Triatoma mazzottii* is reported for the first time in areas distant from the Pacific coast. *Triatoma barberi* was found predominately in the Central Valleys, although this species also occurred occasionally in the upper Mixtecan region, in the north-west corner of the State. Domestic *T. phyllosoma* was found in a region limited on the west by the southern Zapotecan Sierra and to the east by the Isthmus of Tehuantepec, in the Pacific coastal valleys and plain. *Triatoma pallidipennis* is reported from domestic habitats for the first time in Oaxaca, further south

Table 1. Triatomine collection villages in Oaxaca (1996–98).

Village	Municipal key	Longitude	Latitude	Altitude (m a.s.l.)	Triatomine species
Agua Blanca	017	96°47′38″	16°34′25″	1420	*T. barberi*
Arroyo Seco	134	96°32′48″	18°03′41″	130	*T. mazzotti*
Asuncion Lachixila	457	96°10′55″	17°33′45″	560	*T. dimidiata*
Asuncion Tlacolulita	008	95°43′33″	16°17′58″	220	*T. phyllosoma*
Bajo El Arenal	413	96°15′17″	15°42′58″	20	*T. mazzotti*
Bajos de Coyula	413	96°18′22″	15°42′15″	20	*T. mazzotti*
Barra del Potrero	439	96°45′45″	15°44′03″	9	*T. phyllosoma*
Barra del Potrero	439	96°45′45″	15°44′03″	9	*T. mazzotti*
Camalote, El	401	96°52′26″	15°56′02″	100	*T. mazzotti*
Camaron, El	064	96°01′35″	16°33′10″	360	*T. phyllosoma*
Camaron, El	401	96°59′50″	15°52′43″	30	*T. phyllosoma*
Candelaria Yegole	449	96°18′35″	16°29′40″	1140	*T. phyllosoma*
Cerro de la Cruz	171	96°39′35″	18°12′48″	560	*T. mazzotti*
Cerro de la Esperanza	482	97°58′44″	16°12′45″	15	*T. mazzotti*
Cerro la Cruz	439	96°45′51″	15°44′52″	20	*T. phyllosoma*
Charco Seco	401	96°56′30″	15°49′08″	60	*T. bolivari*
Charco Seco	401	96°56′30″	15°49′08″	60	*T. mazzotti*
Chilana, La	072	96°43′15″	16°43′24″	1500	*T. barberi*
Chuxnaban (San Juan Bosco Chuxnaban)	275	95°49′47″	17°01′05″	540	*T. dimidiata*
Ciruelo, El	482	98°15′25″	16°19′04″	20	*T. mazzotti*
Compañia, La	017	96°49′08″	16°33′25″	1380	*T. barberi*
Copalita la Hamaca	266	96°11′17″	15°53′35″	200	*T. mazzotti*
Gavilan, El	057	94°49′50″	17°10′55″	160	*T. nitida*
Guicha	449	96°18′20″	16°27′05″	1200	*T. phyllosoma*
Horcones, Los	012	96°34′35″	15°50′07″	200	*T. phyllosoma*
Ixtepec	014	95°07′12″	16°33′33″	60	*T. phyllosoma*
Jalapa del Valle	135	96°52′41″	17°04′02″	1720	*T. barberi*
Macahuite	439	96°41′30″	15°43′54″	20	*T. phyllosoma*
Maninaltepec (La Ermita)	460	95°50′40″	17°23′50″	560	*T. mazzotti*
Margaritas, Las	333	96°10′15″	16°41′50″	780	*T. phyllosoma*
Merced del Potrero, La	266	96°04′20″	16°02′43″	640	*T. mazzotti*
Mezquite, El	005	94°57′23″	16°41′32″	660	*T. phyllosoma*
Nejapa de Madero	064	95°58′42″	16°36′28″	30	*T. phyllosoma*
Nejapa de Madero	064	95°58′42″	16°36′28″	660	*R. prolixus*
Palma Larga	439	96°45′51″	15°48′10″	120	*T. mazzotti*
Piedra Blanca	482	97°59′50″	16°15′35″	40	*T. mazzotti*
Piedras Negras (Taragutin)	059	96°38′50″	16°23′18″	1520	*T. barberi*
Pueblo Viejo	439	96°44′39″	15°50′41″	220	*T. mazzotti*
Puerto Escondido	318	97°04′00″	15°51′45″	40	*T. mazzotti*
Rojas de Cuauhtemoc	078	96°37′58″	17°00′22″	1570	*T. barberi*
San Agustin Atenango	081	98°00′50″	17°36′36″	1300	*T. pallidipennis*
San Andres Zautla	102	96°51′47″	17°11′10″	1640	*T. barberi*
San Baltazar Guelavila	131	96°18′15″	16°47′45″	1580	*T. barberi*
San Bartolome Loxicha	117	96°42′30″	15°58′08″	760	*T. phyllosoma*
San Carlos Yautepec	125	96°06′22″	16°29′42″	650	*T. phyllosoma*
San Francisco Cozoaltepec	439	96°43′24″	15°48′35″	140	*T. mazzotti*
San Francisco Yovego	457	96°13′25″	17°33′02″	680	*T. dimidiata*
San Isidro	102	96°49′41″	17°11′35″	1610	*T. barberi*
San Isidro	036	95°21′31″	16°50′36″	900	*T. dimidiata*
San Isidro Chihuiro	064	96°02′20″	16°30′48″	640	*T. phyllosoma*
San Isidro Llano Grande	334	97°17′05″	15°57′02″	60	*T. mazzotti*
San Jose Chinantequilla	554	95°59′24″	17°18′25″	1160	*T. dimidiata*
San Jose de Gracia	333	96°05′50″	16°39′28″	720	*T. phyllosoma*
San Jose las Flores	064	95°58′12‴	16°37′44″	280	*T. phyllosoma*
San Jose las Flores	064	95°58′12″	16°37′44″	660	*R. prolixus*
San Juan Bautista Guelache	178	96°46′40″	17°13′35″	1740	*T. barberi*
San Juan Comaltepec	189	95°58′32″	17°20′15″	650	*T. dimidiata*
San Lorenzo Vista Hermosa	261	98°04′05″	17°57′30″	1520	*T. pallidipennis*
San Martin de Porres	064	95°59′30″	16°36′38″	1200	*T. phyllosoma*

Village	Municipal key	Longitude	Latitude	Altitude (m a.s.l.)	Triatomine species
San Mateo Cajonos	246	96°12′25″	17°09′40″	1360	*T. dimidiata*
San Miguel Amatitlan	261	98°01′26″	17°53′28″	1580	*T. pallidipennis*
San Miguel del Valle	560	96°25′05″	17°01′10″	1780	*T. barberi*
San Miguel Quetzaltepec	275	95°45′35″	16°58′22″	1200	*T. dimidiata*
San Miguel Tlamichico	555	96°46′50″	16°55′55″	1520	*T. nitida*
San Pedro Apostol	301	96°43′35″	16°44′10″	1500	*T. barberi*
San Pedro Martir	315	96°42′40″	16°44′34″	1500	*T. barberi*
San Pedro Martir Quiechapa	316	96°14′48″	16°24′50″	1820	*T. barberi*
San Pedro Mixtepec – Distr. 22	318	97°04′58″	15°58′58″	220	*T. mazzotti*
San Pedro Totolapa	333	96°18′30″	16°40′10″	1060	*T. phyllosoma*
San Sebastian Ixcapa	345	98°08′40″	16°32′30″	240	*T. mazzotti*
San Sebastian Tutla	350	96°40′20″	17°03′35″	1530	*T. barberi*
San Sebastian Yutanino	137	97°27′35″	16°47′23″	1220	*T. dimidiata*
Santa Ana	198	95°05′05″	17°03′08″	130	*T. dimidiata*
Santa Catarina Cuixtla	362	96°38′06″	16°18′27″	1700	*T. barberi*
Santa Cruz el Frayle	055	98°06′45″	17°52′00″	1120	*T. pallidipennis*
Santa Cruz Papalutla	380	96°35′02″	16°57′20″	1580	*T. barberi*
Santa Gertrudis	387	96°48′02″	16°47′03″	1460	*T. barberi*
Santa Gertrudis Miramar	515	95°23′30″	16°03′45″	10	*T. phyllosoma*
Santa Maria Colotepec	401	96°56′15″	15°53′50″	50	*T. mazzotti*
Santa Maria Coyotepec	403	96°42′28″	16°57′55″	1540	*T. barberi*
Santa Maria Jicaltepec	482	98°02′38″	16°22′45″	500	*T. mazzotti*
Santiago Jamiltepec	467	97°49′24″	16°16′50″	440	*T. mazzotti*
Santiago Llano Grande	447	97°56′03″	16°40′37″	740	*T. mazzotti*
Santiago Suchilquitongo	483	96°52′00″	17°15′00″	1730	*T. barberi*
Santiago Yosondua	500	97°34′35″	16°52′20″	2200	*T. barberi*
Santo Domingo Chihuitan	508	95°09′42″	16°35′20″	90	*T. phyllosoma*
Santo Domingo Ingenio	505	94°46′00″	16°35′15″	40	*T. mazzotti*
Santos Reyes Nopala	526	97°08′37″	16°06′21″	460	*T. mazzotti*
Soledad Salinas, La	325	95°59′55″	16°39′37″	760	*T. phyllosoma*
Soluta	439	96°44′00″	15°47′05″	80	*T. mazzotti*
Teotitlan del Valle	546	96°31′12″	17°01′45″	1670	*T. barberi*
Tesoro, El	275	95°44′04″	16°58′22″	840	*T. dimidiata*
Tilzapote	439	96°47′35″	15°44′20″	20	*T. mazzotti*
Tlacolula de Matamoros	551	96°28′33″	16°57′13″	1600	*T. barberi*
Tres Rios	085	96°41′28″	15°52′36″	880	*T. phyllosoma*
Tule, El	439	96°49′42″	15°44′25″	40	*T. bolivari*
Victoria, La	189	95°58′37″	17°19′10″	1050	*T. dimidiata*
Villa Sola de Vega	277	97°58′40″	16°30′53″	1400	*T. dimidiata*
Villa Union	439	96°44′14″	15°48′30″	120	*T. bolivari*
Yugoxi	198	95°08′58″	16°59′40″	340	*T. mazzotti*

than previously encountered; people in the upper Mixtecan region report that this distinctive species of bug has always been present in sylvatic habitats. *Triatoma bolivari*, a recently described species (Carcavallo *et al.*, 1987), was found in a restricted area on the Pacific coast, where the distributions of *T. mazzottii* and *T. phyllosoma* overlap and all three species are sympatric. Two adults and one nymph of *T. nitida* were collected from two villages in the Central Valley region (one 60 km south of Oaxaca City, the other > 200 km distant), in a village nestled in the Zapotecan Sierra. Occurrence of this species outside the Yucatan Peninsula may represent displacement due to migrant farmworkers. Three specimens of *R. prolixus* were found in two villages (Table 1) in the Zapotecan Sierra – the first specimens to be collected in Mexico for 18 years.

Distribution ranges for domestic triatomine species

Despite the extensive distributions of the principal domestic triatomine species (*T. barberi, T. dimidiata, T. mazzottii* and *T. phyllosoma*), there was little overlap in their ranges (Fig. 2). Although distribution regions for *T. mazzottii* and *T. dimidiata* overlapped in the upper part of the Isthmus of Tehuantepec and northern Mixe region these two species are associated with different altitude, precipitation and temperature (Table 2). *Triatoma dimidiata* was found at higher altitudes with low mean annual temperatures (650–1440 m a.s.l., 12–26°C), whereas *T. mazzottii* was restricted to lowlands with high mean annual temperature (15–750 m a.s.l., 22 to > 26°C). Habitat partitioning also separates *T. dimidiata* from *T. barberi* in

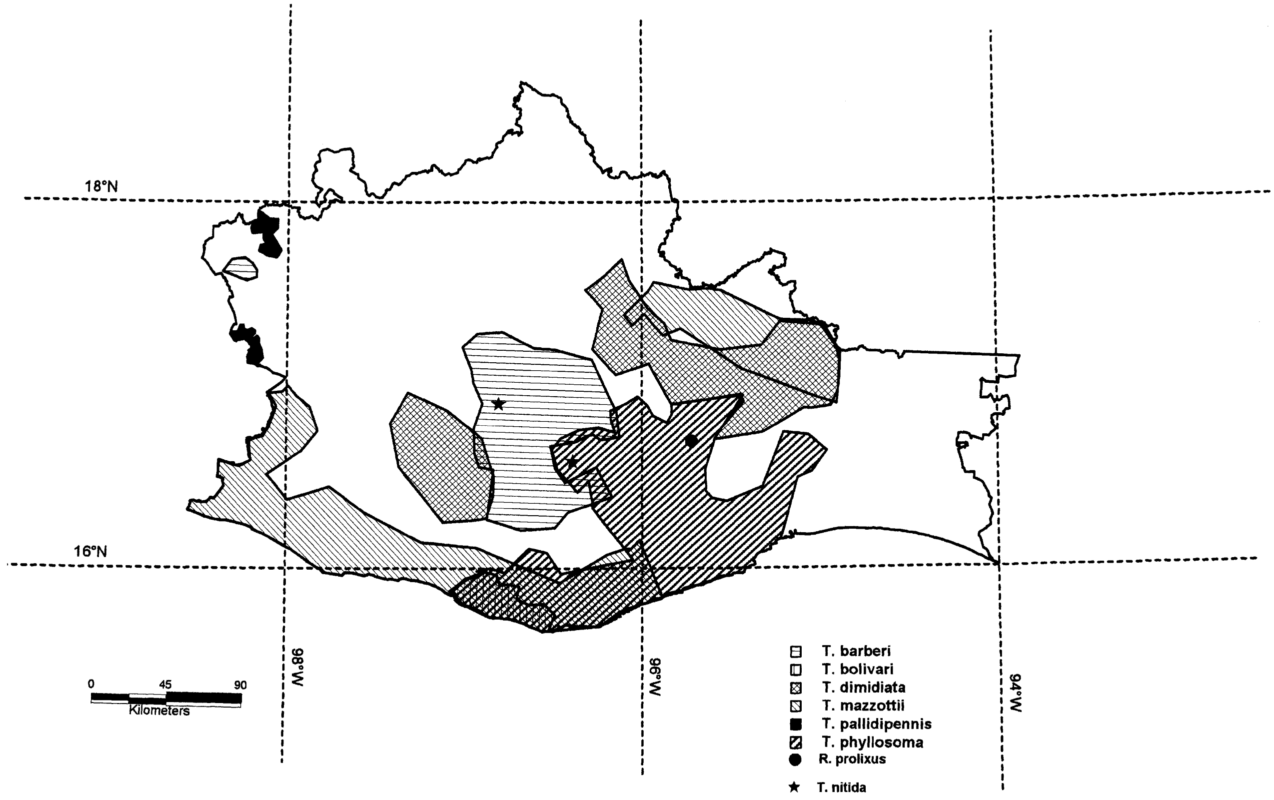

Fig. 2. Distribution of eight species of Triatominae in domestic habitats in the state of Oaxaca, Mexico: *Triatoma barberi*, *T. bolivari*, *T. dimidiata*, *T. mazzottii*, *T. pallidipennis*, *T. phyllosoma*, *T. nitida*, *Rhodnius prolixus*.

Table 2. Geographic indices of villages positive for domestic triatomines in Oaxaca..

	Present study				Previous studies	
Species	Villages (*n*)	Altitude range (m a.s.l.)	Precipitation range[1] (mm)	Temperature range[1] (°C)	Villages (*n*)	Altitude range (m a.s.l.)
T. barberi	27	1420–1780	600–1200	12–22	6	1400–2060[2]
T. dimidiata	13	500–1440	800–2500	12–26	3	580–1000
T. mazzottii	28	15–750	800–2500	22–>26	14	30–860[3]
T. phyllosoma	22	10–1200	600–1500	22–>26	8	20–1060
T. pallidipennis	4	1100–1520	800–1500	18–26	0	–
T. bolivari	3	40–120	800–1200	>26	0	–
T. nitida	2	1100–1520	600–800	18–22	0	–
T. picturata	0	–	–	–	2	20–1000
R. prolixus	2	640–660	600–1200	18–22	5	440–1260

[1]Mean annual; [2]Exception Cuicatlan at 620 m a.s.l.; [3]Exception Santiago Juxtlahuaca at 1680 m a.s.l.

the southern coastal sierra, with *T. barberi* found at higher altitudes (1420–1780 m a.s.l.) than *T. dimidiata* (500–1440 m a.s.l.). *Triatoma pallidipennis* was also found at higher altitudes in in the Mixtecan Sierra. Another example of distribution overlap was shown by *T. phyllosoma* and *T. mazzottii* along the Pacific coast, coinciding with the only region where *T. bolivari* was found in this State.

Entomological indices

Triatoma mazzottii seems to be the predominant vector of Chagas Disease in Oaxaca, in terms of its wide distribution, abundance and higher infection rate with *T. cruzi* (Table 3). Compared with *T. barberi*, usually considered to be the principal domestic vector in Mexico, *T. mazzottii* had a higher

Table 3. Entomological and parasitological indices for principal domestic triatomines.

Species	Villages (*n*)	Bugs (*n*)	Crowding index	Colonization index	Infestation index	Infectivity *T. cruzi*
T. mazzottii	25	223	4.9	0.5	–	33.9%
T. barberi	26	157	2.7	0.5	–	24.4%
T. phyllosoma	22	294	6.0	0.3	7.0	27.2%
T. dimidiata	13	755	10.1	0.9	78.0[1]	3.7%

[1] Average from two villages

rate of *T. cruzi* infection (33.9% vs. 24.4%) but similar crowding and colonization indices. By comparison with other Mexican triatomine species, both *T. mazzottii* and *T. phyllosoma* had relatively high crowding indices (crowding index = 5–6), whereas *T. phyllosoma* less frequently colonized human dwellings: colonization index = 0.3 vs. 0.5 for *T. mazzottii.* The proximity of other habitats (cliffs, rock outcroppings) and permanent presence of livestock near human dwellings, probably help to maintain *T. phyllosoma* infestations (infestation index = 7%) despite low colonization indices. In the case of *T. dimidiata*, despite high indices of crowding (10.1), colonization (0.9) and infestation (> 75%), this species was rarely infected with *T. cruzi*. The overall *T. dimidiata* infection rate was only 3.7% (range 0–14%) and, in some villages where *T. dimidiata* had high infestation and crowding indices, not one was infected with *T. cruzi*.

Among the less prevalent domestic triatomine species, *T. pallidipennis* is potentially the most important. This species is characteristic of the upper Mixtecan region where, although it remains primarily sylvatic, the upsurge in new housing construction in this region may be an important factor encouraging the increasing visibility of *T. pallidipennis* inside human domiciles.

Triatoma bolivari and *T. nitida* were collected only by members of the local communities and have not been studied alive. For *T. bolivari* we suspect that the few specimens came with movement of crop harvests (corn, sugar cane) to the peridomestic areas, because no domestic infestation by this species was encountered. Nymphs of *T. nitida* were observed and collected by villagers in both of the collection sites, indicating that this species probably breeds in habitats surrounding the villages.

Rhodnius prolixus was collected from adobe houses with the roof made from tiles, asbestos or ‘carrizo’ (*Olyra latifolia*). Both villages where this species was collected had previously maintained large plantations of seed palm ‘coyul’ (*Acrocomia aculeata* = *A. mexicana*) and date palms (*Phoenix dactylifera*). Despite several searches, we could not find *R. prolixus* in palm trees.

All three predominant domestic species, *T. mazzottii, T. barberi* and *T. phyllosoma*, had higher crowding indices correlated with increased altitude, whereas the colonization index was positively correlated with altitude only for *T. mazzottii* (Tables 4–6). Village infestation indices were estimated only for *T. phyllosoma*, and found to be inversely correlated with altitude (Table 6). *Triatomine cruzi* infection rates decreased with altitude for *T. mazzottii* and *T. phyllosoma*, but increased with altitude for *T. barberi*. *Triatoma phyllosoma* collected in villages above 800 m a.s.l. were never infected. There were too few collections of *T. dimidiata* to analyse entomological indices in relation to altitude, although it is interesting to note that below 800 m a.s.l. and above 1100 m a.s.l. both the colonization index and *T. cruzi* infection rate were negative.

Table 4. Entomological indices and *T.cruzi* infectivity for *T. mazzottii* ranked according to village altitude (*n* = number of villages).

Altitude (m a.s.l.)	Crowding index	Colonization index	Infectivity *T. cruzi*
0–199 (*n* = 8)	3.1	0.3	40.0%
200–399 (*n* = 3)	3.7	0.5	–
400–700 (*n* = 4)	13.1	0.9	27.2%

Table 5. Entomological indices and *T. cruzi* infectivity of *T. barberi* ranked according to village altitude.(*n* = number of villages).

Altitude (m a.s.l.)	Crowding index	Colonization index	Infectivity *T. cruzi*
1300–1499 (*n* = 3)	2.0	0.3	25.0%
1500–1699 (*n* = 14)	2.6	0.5	22.2%
1700–1899 (*n* = 4)	3.8	0.3	40.0%

Table 6. Entomological indices and *T. cruzi* infectivity of *T. phyllosoma* ranked according to village altitude. (*n* = number of villages).

Altitude (m a.s.l.)	Crowding index	Colonization index	Infestation index	Infectivity *T. cruzi*
0–399 (*n* = 7)	1.6	0.4	8.2%	47.6%
400–799 (*n* = 5)	3.1	0.2	7.3%	66.7%
800–1200 (*n* = 4)	8.7	0.5	5.1%	0%

Stratification of triatomine infestation and transmission risk

Municipalities in Oaxaca were classified according to the altitude of the majority of villages (> 51% of villages located in one altitude category). Five altitude categories were defined, based on the observed altitude limits of domestic triatomine species found: 0–749, 750–1199, 1200–1399, 1400–1849 and > 1850 m a.s.l. More than 80% of villages were located within a single altitude category in 90% (509/570) of municipalities. A stratified topography map was generated using the classification of municipalities for the five altitude categories (Fig. 3). Municipalities having a predominance of more than one altitude category are also represented in this map.

Of the 101 potential *T. mazzottii*-infested municipalities, classified with altitudes between 0 and 749 m a.s.l. (altitude category 1), five are isolated and surrounded by municipalities of higher altitude categories and are therefore located outside potential dispersion areas. While seven have a mean annual precipitation > 4 m, two have mean annual precipitation < 0.8 m, and three have mean annual temperatures below the species apparent range (< 22°C). Among the remaining 84 municipalities, 30 are located in the area of the Pacific coastal isthmus region characterized by extremely high winds, or the Chimalapa forest region characterized by low density human populations. Collections from 12 municipalities reported in the present study confirmed two distribution regions spanning 38 of the 54 potentially infested municipalities.

Preliminary analysis of *T. barberi* distribution, based only on topography (municipalities classified between 1400 and 1850 m a.s.l., Fig. 3, category 4), predicts three potential regions for this species: one in the Central Valleys (134 municipalities), another in the upper Mixtecan region (28 municipalities) and a third in the northern Cuicatlan region (12 municipalities). In fact, *T. barberi* was collected from the first two regions, the most complete collections originating from the Central Valleys (Fig. 4). Analysis of this latter area reveals that the 134 potentially infested municipalities are surrounded by others where the villages are either too low (43) or too high (47) in altitude to support the species. Within the area defined by the 134 at risk municipalities in the Central Valleys, 20 have been confirmed infested with *T. barberi*.

The altitude range of *T. phyllosoma* is wider than that of the previous two species; the mapping of potentially infested municipalities includes altitude categories 1 and 2. This represents all of the area previously mentioned for *T. mazzottii* (101 municipalities) and an additional 62 municipalities at higher altitudes (800–1200 m a.s.l.). However, *T. phyllosoma* was not collected in areas where the annual precipitation exceeds 1.5 m, offering an additional criterion which excludes all municipalities in the northern region of the state, and

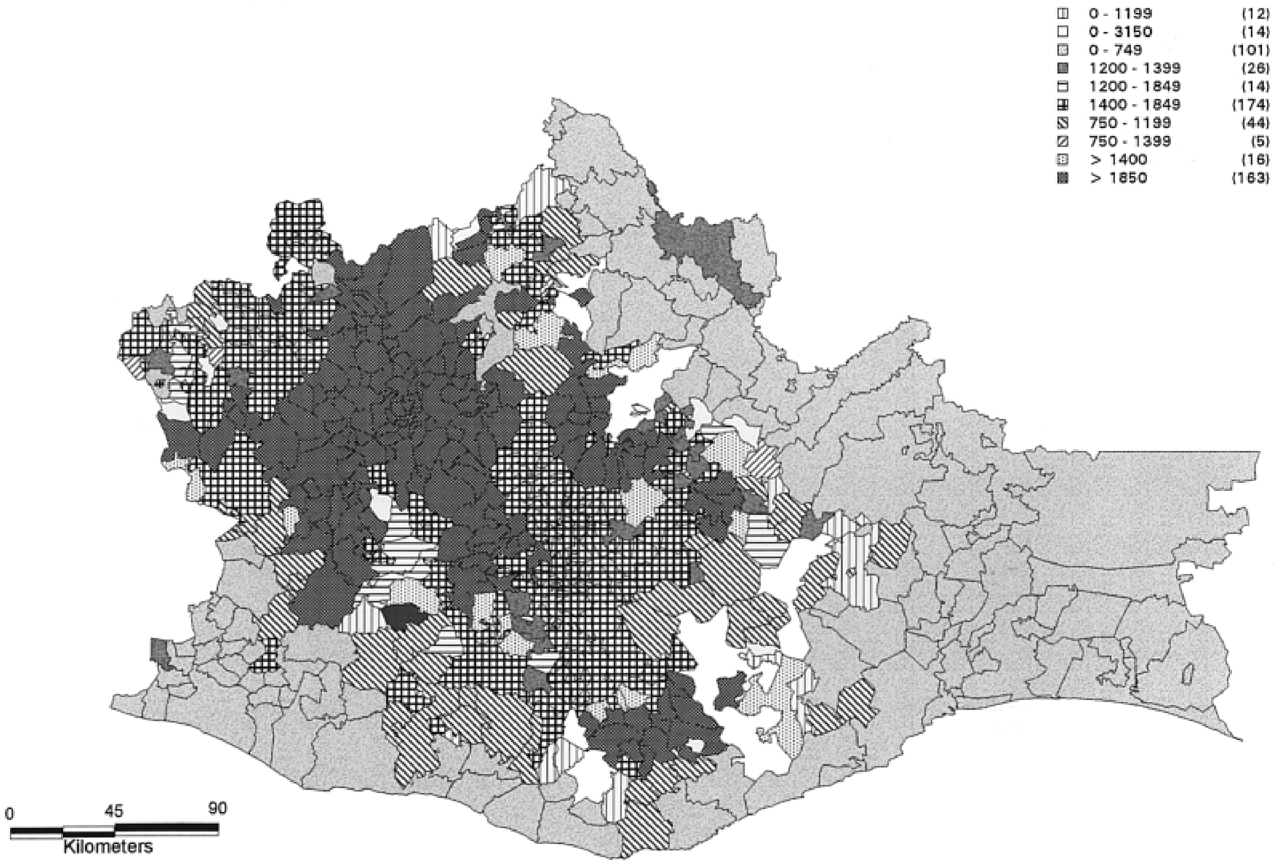

Fig. 3. Topography of Oaxaca municipalities, based on five primary altitude strata in metres above mean sea level: 0–749, 750–1199, 1200–1399, 1400–1849, > 1850 m a.s.l.

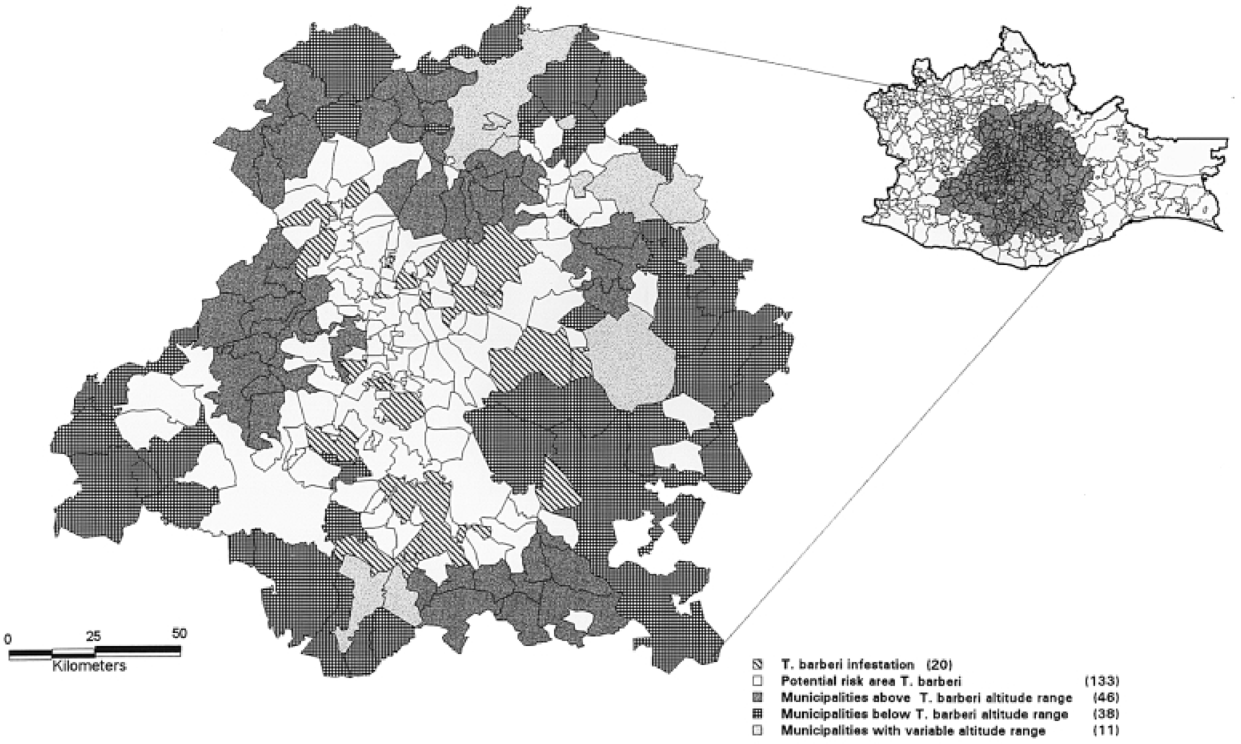

Fig. 4. Topography of *Triatoma barberi*-infested municipalities of the Central Valleys region of Oaxaca, Mexico. Perimeter of the region is composed of municipalities above or below the altitude range for this species (1400–1850 m a.s.l), while 20 of 153 municipalities in the risk area have confirmed domestic infestation.

confines the potential dispersion area to an arc overlapping the area defined by the collections reported in the present study. This area predicts a potential at risk area covering 43 municipalities.

In much the same manner, *T. dimidiata*-infested areas cannot be predicted by altitude alone. Four primary areas could be predicted by altitude: (i) the area infested by *T. phyllosoma*, (ii) a small area east of the predicted *T. barberi*-Cuicatlan area, (iii) west-south-west of the Central Valleys along the southern Sierra, and (iv) the region north-east of the Central Valleys into the northern isthmus region. However, *T. dimidiata* was found only in the latter two areas. As *T. dimidiata* was associated with mean annual precipitation of 1.2–4 m, lower rainfall might account for absence of this species in the Zapotecan Sierra region where *T. phyllosoma* is found.

The distribution of domestic Triatominae based on our collection data was used to indicate areas of potential risk for transmission of *T. cruzi* to humans (Table 7). High transmission risk areas were defined by the presence of one of the two primary vector species: *T. barberi* or *T. mazzottii*. These areas include 71% of people at risk (1 330 410 population) and represent major tourism and important agricultural areas. The presence of *T. phyllosoma* represents medium (0–750 m a.s.l., coastal plain) or low (750–1200 m a.s.l., Zapotecan Sierra) risk; *T. pallidipennis* represents medium risk, while *T. dimidiata* gives little (650–1200 m a.s.l.) or no (1200–1450 m a.s.l.) risk. Using the species distribution maps, and including only those communities located at appropriate altitudes, indicates that 4418 communities with a population of 1 874 320 are considered to be at risk of *T. cruzi* through vector transmission in Oaxaca. If potential risk areas predicted by precipitation, temperature and house-type (socio-economic status) are included, irrespective of altitude, the population at risk rises to 2 148 100. Using available seroprevalence data from some of these areas (Table 7), we estimated that 134 280–154 440 individuals are currently infected with *T. cruzi* and that ≈ 40 280–51 480 individuals probably have some form of chronic chagasic symptoms.

Discussion

Reviews of triatomine distribution in Mexico by Zarate & Zarate (1985) and in Oaxaca by Goldsmith *et al.* (1978) cited six species in the State: *T. barberi, T. dimidiata, T. mazzottii, T. phyllosoma*, *T. picturata* and *R. prolixus.* Of these, five remain present. Previous reports of *T. picturata* in Oaxaca (Biagi & Navarrete, 1960) probably represent misidentification, as one of their records corresponds to the village of Chiquihuitlan where only *T. dimidiata* was found, and the other to Juchitan in the Isthmus where only *T. phyllosoma* is present. As noted by Zarate & Zarate (1985), *T. picturata*

Table 7. Populations at risk of Chagas Disease transmission by vectors, estimated current infected population and estimated population with chronic disease in Oaxaca.

Altitude (m a.s.l.)	Vector	Transmision risk[1]	No. of villages	No. of dwellings	Population at risk	Infected population	Chronic disease
0–750	*T. mazzottii*	H	2114	111 274	579 806	75 375[2]	22 612
	T. phyllosoma	M	643	74 798	353 591	32 634[3]	9790
750–1200	*T. phyllosoma*	L	332	7842	38 922		
	T. dimidiata	L	162	3843	20 948		
1200–1400	*T. dimidiata*	L/0	177	12 452	62 781		
	T. pallidipennis	M	69	6003	30 538		
1400–1850	*T. pallidipennis*	M	134	7224	37 127		
	T. barberi	H	787	157 294	750 607	26 271[4]	7881
Total			4418	380 630	1 874 320	134 280	40 284

[1] H = high, M = medium, L = low, 0 = 0 risk.
[2] Seroprevalence: 13%
[3] Seroprevalence: 6%
[4] Seroprevalence: 3.5%

could be readily confused with either species, and our extensive surveys along the coast of Oaxaca from Guerrero to the Chiapas border have never resulted in the collection of *T. picturata*.

The previously published distribution of the four primary triatomine species reported from Oaxaca does not vary significantly from that presented herein, with the exception that there seems to have been a spread of *T. mazzottii* to northern areas of the state. *Triatoma mazzottii* has been the most extensively studied species of bug in Oaxaca, reported previously from 14 towns in the altitude range 30–860 m a.s.l. All of the former collections of this species fall within the Pacific coastal range, as confirmed here. It is interesting to note that populations from the original coastal areas and the newly infested northern region occur in areas of similar altitude and precipitation. A similar area of the upper Chimalapa region of the isthmus has not been studied and may become similarly infested.

Triatoma barberi had been reported previously from only six villages in Oaxaca, within the altitude range 1400–2060 m a.s.l. One exception was a report from Cuicatlan, located at 620 m a.s.l. (Tay, 1969) and, except for this, all previous reports of *T. barberi* are from within the Central Valleys. *Triatoma dimidiata* was reported previously only three times from the State, from localities corresponding to those confirmed in the present study and within a similar altitude range (580–1000 m a.s.l). Despite the confusion of subspecific classification of the phyllosoma complex prior to 1979, it appears that *T. phyllosoma* had been collected from only four towns in Oaxaca (Tehuantepec, Juchitan, Salina Cruz, San Pedro Totolapan). Samples of the two most similar members of the phyllosoma complex were carefully classified by Mazzotti (1940b) as either short-winged (*T. phyllosoma*) or long-winged (*T. mazzottii*) varieties, although this distinction was not noted during previous reviews (Tay, 1980; Zarate & Zarate, 1985), and *T. phyllosoma* was reported incorrectly from multiple villages where only *T. mazzottii* is present (Pocitos Collantes, San Francisco Cozoaltepec, San Pedro Tututepec). We find that these two species do have overlapping distributions and are sympatric in at least one village, Cerro de la Cruz, in the coastal area of Santa Maria Tonameca.

In addition, we can now confirm the presence of *T. pallidipennis*, *T. bolivari* and *T. nitida* in domestic or peridomestic habitats in Oaxaca. The most important of these is *T. pallidipennis*, which is a widespread domestic vector in Mexico, ranging from the state of Nayarit in the north, spanning the Pacific coastal plain to Guerrero, and the high plains south to Oaxaca. One previous report of this species from Veracruz (H. Brailovsky, personal communication, 1973) may therefore have been real, and not storm distribution as previously suggested (Zarate & Zarate, 1985). The progressive domestication and southern expansion of *T. pallidipennis* may be related to the increased use of brick and cement blocks in new housing, even in rural areas since the 1970s. *Triatoma pallidipennis* and other members of the phyllosoma complex are generally associated with sylvatic rock habitats, so adaptation to brick and cement constructions seems a relatively simple step.

Triatoma bolivari was first described by Carcavallo *et al.* (1987) based on male insects collected at light traps from localities in Colima, Nayarit and Jalisco, Mexico. Females had not been previously collected, and the sylvatic habitats of this species remain unknown. Although males and females of *T. bolivari* have now been collected both inside and outside dwellings along the Pacific coast in Oaxaca, these collections have always coincided with the presence of fresh crop harvests in the peridomiciliary area. Despite extensive village searches where samples had been collected by inhabitants, no live insects were observed inside houses and no sylvatic foci of this species have yet been identified.

A similar situation has occurred with *T. nitida*, where fortuitous collections by inhabitants in the area of Zaachila south of Oaxaca City, and in Santa Maria Zoquitlan, have only resulted in the collection of isolated samples; attempts to collect live insects within houses have not succeeded. As the Isthmus of Tehuantepec is the funnel for population migrations from Central America, including Guatemala and Honduras where *T. nitida* is often found associated with peridomestic animals, this species may have been imported from the south. However, nymphs were also found inside houses, which might indicate establishment of *T. nitida* in the region. Housing materials are primarily adobe in both villages where *T. nitida* was collected and, as occurs in many rural areas of Mexico, farmers maintain both large and small animal corrals juxtaposed to village houses in order to prevent livestock theft. Animals are shepherded periodically to surrounding areas, and then returned to the peridomicile corrals. This practice is responsible for an increase in both *T. pallidipennis* and *T. barberi* infestations in rural villages in the state of Morelos (Ramsey, unpublished data).

Hitherto, the last specimen of *R. prolixus* collected in Mexico was found in Oaxaca in 1980 (S. Ibañez, personal communication), although the most recent published collection was reported from Cerro del Aire by Goldsmith *et al.* (1978). This species can no longer be found in most of its previously reported sites (Santiago Jamiltepec, Putla, Cerro del Aire) and only three examples of this species, collected between July and September 1998, were found in our study from two villages near a previously reported collection site (San José de las Flores).

A marked macrohabitat partitioning occurs among most triatomine species in Oaxaca. However, geographical topography alone does not correlate with the distribution patterns of triatomine species, although it probably influences the location of human settlements. Most municipalities in Oaxaca contain settlements at similar altitudes, despite highly variable topography, and mean annual precipitation seems an important determinant of species distribution – especially in the case of *T. mazzottii, T. phyllosoma* and *T. dimidiata*. Combined, altitude and precipitation can be used to identify localities where one of the main vector species may be expected, reducing by less than half the municipalities which will require further entomological and/or seroepidemiological studies. As more information regarding each species becomes available, distribution ranges, altitude and precipitation restrictions, as well as the importance of temperature and vegetation types, can be further incorporated into macrohabitat stratification criteria.

Decentralization of the Mexican PHC service in 1997 coincided with the first proposals for a national Chagas Disease Control Program. Since 1992, the Mexican Public Health law mandates the screening of all blood donations from endemic areas. The National Vector Control Program specifies reporting of triatomines by vector control personnel, but State authorities have difficulty providing appropriate resources. In order to assign priority to Chagas Disease surveillance and control, the States of Mexico need data for comparing the Chagas Disease burden and treatment costs with other requirements of the health sector. This study constitutes the first attempt to analyse Chagas Disease risks and burden in Mexico, based on vector transmission potential in the state of Oaxaca. We estimate that, in Oaxaca alone, Chagas diagnostic tests on >130 000 cases and treatment of >40 000 patients (Table 7) would cost at least US$1.6 million, while the disease represents an overall burden of disability adjusted life years (DALYs) costing almost US$30 million.

Acknowledgements

The authors would like to thank all primary healthcare and entomology personnel in Oaxaca who have participated in this study and particularly recognize the invaluable collaboration of Andres Reyes and Faustino del Villar. We appreciate the motivational and pioneering discussions of Dr Jorge Tay regarding geographical determinants of infestation, and enlightening discussions with Sergio Ibañez and Paz Maria Salazar regarding Chagas Disease transmision in Mexico. This study was financed by Mexican Secretary of Health institutional and State budgets and benefited from international collaboration through the ECLAT network.

References

Brodie, H.D. & Ryckman, R.E. (1967) Molecular taxonomy of Triatominae (Hemiptera. *Reduviidae). Journal of Medical Entomology*, **4**, 497–517.

Biagi, F. & Navarrete, F. (1960) Estado actual de nuestros conocimientos sobre la enfermedad de Chagas en México. I. Transmisores. *Annals del Congreso Internacional da Doenca de Chagas*, **1**, 285–289.

Brumpt, E., Mazzottii, L. & Brumpt, L.C. (1939) Enquetes epidemiologiques sur la maladie de C. Chagas au Mexique (1). Reduvidés vecteurs, animaux reservoirs de virus, cas humains. *Annals of Parasitology*, **17**, 299–312.

Carcavallo, R., Martinez, A. & Peláez, D. (1987) Una nueva especie de *Triatoma* Laporte de México. *Chagas*, **4**, 476–477.

Dias, E. (1951) Doenca de Chagas nas Americas II. México. *Revista Brasileña de Malariologia y Doencas Tropical*, **3**, 355–570.

Goldsmith, R.S., Kagan, I.G., Zarate, R.J., Reyes Gonzalez, M.A. & Cedeño Ferreira, J. (1978) Epidemiological studies of Chagas disease in Oaxaca, Mexico. *Bulletin of the Pan American Health Organization*, **12**, 236–250.

Gomez-Nunez, J.C. (1965) Desarrollo de un nuevo metodo para evaluar la infestacion intradomiciliaria por *Rhodnius prolixus. Acta Cientifica Venezolano*, **16**, 26–31.

INEGI (1995) *Annuario Estadistico del Estado de Oaxaca*, Instituo Nacional de Estadistica, Geografia e Información, Mexico.

Little, J.W., Tay, J. & Biagi, F. (1966) A study on the susceptibility of triatomid bugs to some Mexican strains of *Trypanosoma cruzi*. *Journal of Medical Entomology*, **3**, 252–255.

Martinez, P.M.L. & Martin, F. (1981) Una nueva cepa de *Trypanosoma* tipo *cruzi*, con localización peritoneal preferente. *Revista de Salud Publica de México*, **23**, 23–24.

Mazzotti, L. (1940a) Dos casos de enfermedad de Chagas en el estado de Oaxaca. *Gaceta Medica Mexicana*, **70**, 417–420.

Mazzotti, L. (1940b) Triatomideos de México y su infección natural por *Trypanosoma cruzi* Chagas. *Revista de Medicina Mexicana*, **20**, 95–109.

Mazzotti, L. & Dias, E. (1949) Resumen de los datos publicados sobre la enfermedad de Chagas en Mexico. *Revista de la Sociedad Mexicana de Historia Natural*, **10**, 103–111.

Mazzotti, L. & Osorio, M.T. (1942) Cruzamientos experimentales entre varias especies de triatomas. *Revista de Medicina Mexicana*, **22**, 215–222.

PAHO (1997) *Health of the Americas*. Pan American Health Organization, Washington.

del Rey, E.C., Basombrio, M.A. & Rojas, C.L. (1995) Beneficios brutos de la prevención del Mal de Chagas. *Castañares-Cuadernos del IIE,* Cuad. 4, Año III, Buenos Aires.

Salazar Schettino, P.M., de Haro Arteaga, I. & Uribarren Berrueta, T. (1988) Chagas disease in Mexico. *Parasitology Today*, **4**, 348–352.

Schofield, C.J. (1991) A cost-benefit analysis of Chagas disease control. *Memorias de Instituto Oswaldo Cruz*, **86**, 285–295.

Schmunis, G. (1996) La Tripanosomiasis americana como problema de salud pública. *Pan American Health Organization Publication*, **547**, 3–31.

Tay, J. (1969) Localidades nuevas de triatominos mexicanos y su infección natural por *Trypanosoma cruzi*. *Revista de Medicina Mexicana*, **49**, 35–43.

Tay, J. (1980) La enfermedad de Chagas en la República Mexicana. *Revista de Salus Pública Mexicana*, **22**, 409–450.

Tay, J. & de Biagi, A.M. (1964) Localidades nuevas de triatominos mexicanos y su infección natural por *Trypanosoma cruzi*. *Revista de la Facultad de Medicina*, **6**, 305–311.

WHO (1991) *Control of Chagas Disease*. Technical Report Series 811. World Health Organization, Geneva.

World Bank. (1993) *Investing in Health Research and Development*. Oxford University Press, Oxford.

Zarate, L.G. & Zarate, R.J. (1985) A checklist of the Triatominae (Hemiptera: Reduviidae) of Mexico. *International Journal of Entomology*, **27**, 102–127.

Accepted 10 July 1999