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ORIGINAL ARTICLE

Understanding and managing sanitary risks due to rodent zoonoses in an African city: beyond the Boston Model

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Abstract

The Boston Model describes a successful rodent management plan that succeeded in a first-world city in the USA. In third-world cities, which often contain informal shack settlements, it is debatable whether the Boston Model would apply. In Durban, a major harbor city of three million people on the east coast of South Africa, we investigated the sanitary risks due to rodents in both formal (residential and commercial) and informal (shacks) sectors, and we evaluated the relative merits of different management interventions suggested by the Boston Model. Blood and tissue samples of six species (*Rattus norvegicus*, *R. tanezumi*, *R. rattus*, *Mus musculus*, *Mastomys natalensis*, *Tatera brantsi*) from 262 live-trapped rodents from 54 localities were tested for antibodies or DNA for plague (n = 193: antibody test), leptospirosis (n = 221 for antibody test; n = 69 for polymerase chain reaction test for DNA) and toxoplasmosis (n = 217: antibody test). We conducted a socioeconomic survey of 90 household to determine environmental and socioeconomic disease risk factors in the shack settlement of Cato Crest . No rodents were seropositive for plague, but nine Norway rats, *R. norvegicus* (4.1% of the sample tested) were seropositive for toxoplasmosis, and 22 *R. norvegicus* (10.0% of sample tested) were seropositive for leptospirosis. Disease endemic areas were concentrated in Cato Crest and the commercial district of Durban. Serology tests of humans living in Cato Crest (n = 219) showed 0% exposure to plague, 23% to leptospirosis and 35% to toxoplasmosis. Compared with shack-dwellers, the residents of brick houses had slightly lower levels of exposure to leptospirosis and toxoplasmosis. Based on our results, environmental hygiene and rodent-trapping campaigns were launched in Cato Crest. The initiative owes much of its current success to implementation of the principles inherent in the Boston Model, even though certain elements were lacking.

Key words: Durban, leptospirosis, plague, rodent zoonoses, toxoplasmosis.

INTRODUCTION

"Urban rodent control in the 21st century must focus on a program approach that is both strategic and comprehensive (i.e. proactive rather than reactive)" (Colvin & Jackson 1999)

The world's urban population is set to rise by 2.1 billion by 2030, and such urban population explosions will inevitably favor commensal rodents, especially in those areas least able to cope, such as informal settlements without adequate sewage, housing or infrastructure. This situation will increase the risk of zoonotic disease

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transmission, rat bites and structural damage (Meyer 2003). In spite of this risk, urban rodents are very poorly studied, often because urban areas are "a distasteful setting for mammalian ecology" (Colvin & Jackson 1999).

The "Boston Model" describes a successful rodent management plan that succeeded in a first-world city, Boston, Massachusetts, USA. The plan was implemented in 1990 during the construction of a new highway. This model is widely regarded to be successful because of its centralized approach, well-defined responsibilities and firm accountability (Colvin & Jackson 1999; Fig. 1). Four components specifically contributed to its success: (i) primary management function: biologists trained in the fields of rodent control, geographic information systems (GIS) and contract management; (ii) municipal functions: enforcement of bylaws, refuse removal, environmental sanitation; (iii) pest control contractors: baiing, trapping, monitoring; and (iv) public participation championed by community leaders and non-governmental organizations: public outreach and education, community meetings, door-to-door visits, literature, recognition of cultural differences. Figure 1 shows a flow chart for the Boston Model adapted from Colvin and Jackson (1999). While applicable to at least one first-world city (Boston), its applicability to third-world situations (particularly informal "squatter" or shack settlements that lack infrastructure) has yet to be tested. From Figure 1, it is immediately obvious that certain elements are lacking in an informal settlement (e.g. sewer services, private pest controllers, neighborhood services).

A key concern with rodent infestations in dense urban settlements is the expected (but often unknown) human health risk. Rodents are known reservoirs for at least 60 zoonotic diseases, including plague, leptospirosis, toxoplasmosis, rat typhus, lungworms, arenaviruses and hantaviruses (Begon 2003). Although some, such as plague, have been known for centuries (there are still between 1000 and 3000 human plague cases per year), many others are classified as emerging infectious diseases (Mills 1999; Begon 2003; Singleton *et al.* 2003). Within a recent 5-year period, some 25 new zoonotic arenaviruses and hantaviruses were discovered (Mills 1999). Although lack of hygiene, close proximity of rodents to humans and their food supplies, and high rodent densities would be expected to lead to potential disease epidemics, data on actual disease prevalence in rodents and humans, and their environmental and socioeconomic correlates, are very sparse worldwide for both rural and urban communities (Mills 1999; Singleton *et al.* 2003).

Figure 1 Diagram illustrating the components of the Boston Model (from Colvin & Jackson 1999).

This study is the first to investigate the sanitary risks due to rodent zoonoses (for three selected zoonotic diseases: plague, leptospirosis and toxoplasmosis) in both formal (commercial, industrial, harbor and formal residential areas) and informal (squatter camp) situations, in a third-world city, Durban, South Africa.

Plague (*Yesinia pestis*) is a disease that is spread by certain flea species that live on rats (WHO 1999). This disease allegedly killed many millions of humans during three major pandemics: (i) in the 6th and 7th centuries; (ii) from the 14th to the 17th centuries; and (iii) in the late 19th and early 20th centuries (WHO 1999; Begon 2003). Currently, approximately 1000–3000 human cases are reported annually (Begon 2003). The latest pandemic during the time of the Anglo-Boer War (1900–1901) resulted in high mortality in South Africa. Infections were traced to horse fodder that was imported from Britain via the Durban Harbour and sent to the war front to supply English horses (L. Arntzen, personal communication). Being a major port, the threat of plague reaching Durban is a constant one, with ships from plague-endemic countries arriving at the port frequently. City Health and SA Ports authorities cooperate to ensure that ships from plague-endemic countries are constantly monitored to prevent rats from leaving them, and baiting campaigns are intensified to kill any possible infected rodents leaving ships.

Leptospirosis is spread in the urine of infected rodents and can be transmitted to humans through cuts, abrasions, sores, the eyes and the mouth (WHO 2003). Leptospirosis can be contracted by playing in or drinking contaminated water and by eating contaminated food. The disease is spread by spirochete bacteria of the *Leptospira* genus and can be effectively treated with antibiotics.

However, the symptoms are similar to many other tropical diseases, including malaria, and therefore the disease often goes undiagnosed and untreated (WHO 2003). In immune-suppressed individuals, such as those with AIDS, the disease can be fatal if untreated. The bacteria can survive for a short period outside the host in water bodies and damp soils with a pH of between 7.0 and 8.0. The optimum pH for the bacterium is 7.2 (Smith & Turner 1961; R. Hartskeel, personal communication).

Toxoplasmosis is a protozoan disease caused by the organism *Toxoplasma gondii*. The main host is the domestic cat, where the organism is able to sexually reproduce (Dubey & Beattie 1988). Cysts are shed in cat feces, which are then consumed by other animals, such as rodents. The cysts become encapsulated in the secondary host and the life cycle is completed when a cat eats rodents with encapsulated cysts, which then become activated again.

Toxoplasmosis can be spread to humans through contact with infected cat feces (e.g. by cuddling and stroking domestic cats or from contact with cat litter), or by eating uncooked infected rodents or meat from infected livestock. Although the disease is usually benign in humans, immune-compromised individuals such as the very young and elderly and those with AIDS cannot encapsulate the cysts, which can then be reactivated in the brain and continue to multiply, causing insanity and death. If toxoplasmosis infection occurs for the first time in a pregnant woman, it can result in fetal abnormalities and/or miscarriage (this form of the disease is referred to as congenital toxoplasmosis; Dubey & Beattie 1988).

Durban, with a population of 3.02 million and an area of 2300 km^2, has the busiest harbor in South Africa, one of the world's ten largest. Rodent control efforts currently target the central harbor and commercial districts of the city. However, rodent populations are known to be increasing in informal markets and burgeoning shack settlements that have sprung up throughout the wider municipal area, particularly over the past two decades. It is estimated that some 156 500 households occupy 500 shack settlements throughout the municipal area (eThekwini Municipality, personal communication. These are mostly very small but vary considerably in size and occur on the fringes of, and often within, formal residential areas (Fig. 2a). The number of public complaints about rats has increased noticeably in recent years, and media reports have highlighted increasing concerns about public health risks (especially the risk of plague) and structural damage to property and electronic cabling networks for the city's communication and information

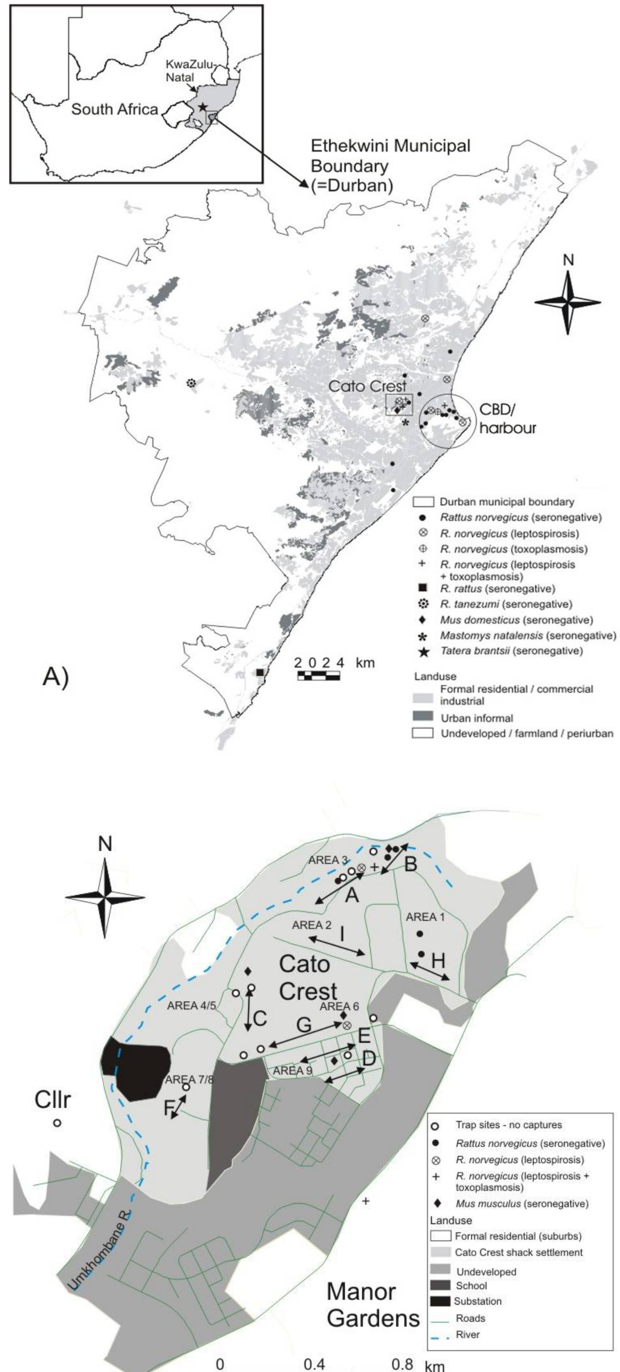

Figure 2 Distribution of rodent species captures in Durban (eThekwini Municipal Region), South Africa, and distribution of rodents seropositive for leptospirosis and toxoplasmosis in (a) the greater Durban area and (b) Cato Crest. Lines A to I represent the transects of the 10 households each used for the socioeconomic survey. CBD, central business district; Cllr, a local councillor's house.

technology systems.

We ask three central questions: (i) Based on serological and polymerase chain reaction (PCR) tests for the three selected diseases in sampled rodents and humans, do urban pest rodents pose a real public health risk? (ii) Are there specific endemic disease areas ("hotspots") for rodents and humans and what are the environmental and socioeconomic correlates of these? (iii) How can rodents be managed in urban (formal and informal) settings to minimize the sanitary risk to humans? To answer these questions required a multidimensional approach that combined laboratory serological analyses, taxonomic identification of rodent specimens (which were all deposited in the collection of the Durban Natural Science Museum), tests of soil pH, GIS analysis and socioeconomic and anthropological surveys. This study forms part of the much wider "Ratzooman" (Rodent Zoonosis Management) Project (www.nri.org/ratzooman/), under the auspices of which the sanitary risks associated with rodents in 14 sites in four African countries were investigated between 2003 and 2006.

MATERIALS AND METHODS

Rodent trapping and testing

A total of 262 rodents were collected using custom-built, wire-mesh, multi-capture live-traps (approximately 60 cm × 20 cm × 20 cm; belonging to the City Health's Communicable Diseases Department) and standard Sherman live-traps (belonging to the Durban Natural Science Museum) from 54 sites throughout the greater Durban area and just beyond its borders (Fig. 2). Live-traps were pre-baited for 1–3 days and then baited with bread and a variety of vegetables, whereas Sherman traps were baited using a mixture of rolled oats, peanut butter and vegetable oil. With the exception of one rodent (*R. norvegicus*) that was trapped opportunistically in the roof of a suburban house using a live-trap, all traps were set on the ground along obvious rodent pathways and close to food sources. Trap sites encompassed the harbor, commercial and industrial districts, and formal and informal residential areas. A total of ten trapping sessions (lasting between 2 and 10 trap-nights each) were carried out between April 2004 and November 2005. Notes were kept of the number of multi-capture and Sherman traps set per night so as to maintain a record of trap effort. Although much of the collecting outside Cato Crest was opportunistic (depending on captures from vector control teams who responded to public complaints about rodent hotspots), the selection of trap sites in Cato Crest was planned to correspond as far as possible with predetermined transects used for the socioeconomic study. As far as possible, an attempt was made to standardize trap effort between sites by setting the same number of multi-capture ($n = 1$) and Sherman traps ($n = 3$) per night and per site (household).

After capture, each rodent was killed using ether, and blood, liver, kidney, heart, lung and spleen tissues were removed and placed in labeled Eppendorf vials. Whole-blood samples were kept at 4°C. Lung and heart tissues were kept frozen at –20°C. Kidney, liver and spleen tissues were kept in 90% ethanol at 4°C. Fleas were collected with forceps after spraying the fur with 70% ethanol, and then stored in 90% ethanol. Skulls were removed and cleaned, and carcasses were preserved initially in 4% formalin for 2 weeks and then transferred into 70% alcohol for long-term storage. All specimens were deposited in the Mammal Collection of the Durban Natural Science Museum. Specimens were identified using current keys and descriptions (De Graaff 1981), assisted by cytochrome b gene sequence analysis of some specimens in the laboratory of the University of KwaZulu Natal (thus we were able to detect the presence of a cryptic species, *Rattus tanezumi*, which was not previously known to occur in Africa; Bastos *et al*., personal communication).

Blood samples were tested at the National Institute for Communicable Diseases (South Africa) for plague (competitive blocking enzyme-linked immunosorbent assay for detection of anti-F1 antibody), toxoplasmosis (Pastorex latex particle agglutination test; Bio-Rad, Paris, France) and leptospirosis (LeptoTek Dri-Dot particle agglutination test; BioMerieux, Boxtel, The Netherlands). Serological tests were conducted on 193 individual rodent samples for plague, 217 for toxoplasmosis and 221 for leptospirosis. A PCR test for the presence of pathogenic *Leptospira* species bacteria in kidney tissue was conducted on 69 samples (Murgia *et al*. 1997). Confirmatory microagglutination antibody tests for pathogenic serovars of leptospires were also performed on some specimens (Onderstepoort Veterinary Research Institute, Pretoria), but these results are pending and will be reported separately.

Human testing

Under ethics permits from the University of the Witwatersrand, Johannesburg and the eThekwini Health Department, serum samples were obtained voluntarily from 217 Cato Crest residents. After appropriate briefing, informed, signed consent in their home language of isiZulu was obtained from each donor. Serological tests for plague, toxoplasmosis and leptospirosis were carried out by the National Institute for Communicable Diseases as described for the rodents.

Soil pH

Soil samples were obtained from between two and four points in the vicinity of each transect near dwellings. In addition, "natural" samples were obtained (some distance from any dwelling) in two natural soil types: Berea red sands and Dwyka tillite-derived soil. In the laboratory, 10 mL dry soil was added to a 50 mL Falcon tube, together with 15 mL distilled water. Tubes were automatically shaken for 1 h and then pH was obtained using a pH meter calibrated to pH 7.

Socioeconomic and anthropological factors

The socioeconomic study in Cato Crest was carried out by staff, students and volunteers from the Durban Natural Science Museum, University of KwaZulu-Natal, and the Natural Resources Institute (University of Greenwich). Using a stratified, random-sampling approach, questionnaires were completed by 90 households (10 households per transect and nine transects), with the assistance of two trained enumerators. Transects were chosen throughout the settlement to correspond as far as possible with rodent trapping sites and to include both valley bottoms (transects A and B) and hill slopes (other transects, C–I), as well as shacks (transects A–C and G–I), and more recently constructed, electrified brick houses (transects D and E; Fig. 2b). Standard questions (approximately 50) were divided into three main categories: (i) socioeconomic status (e.g. social indicators, cultivation of crops, possession of cats and other household animals, housing quality and methods and materials of construction); (ii) human behavior (e.g. nature and source of drinking and washing water, method of sanitation and waste disposal, method of food and water storage and use); and (iii) rodent observations (e.g. frequency of sightings and frequency of bites inflicted on household members, eating of rodents, perceptions about rodent diseases and other rodent-related problems, and methods of rodent control)(Appendix I). The duration of each household interview (i.e. the time taken to complete each questionnaire) was between 30 and 60 min. A detailed report of the results of this socioeconomic survey is available from Iles (2006; available from www.nri.org/ratzooman).

In-depth interviews were carried out for ten Cato Crest families (subset of the sample used for the socioeconomic study) by an anthropology student from the University of KwaZulu-Natal, supervised by Prof. Suzanne Leclerc-Madlala and Dr Monica Janowski. The results of this study, which were very informative in guiding our dealings with the community and suggesting appropriate, culturally sensitive rodent control and awareness measures, are not reported in detail here but are available from Janowski (2004; available from www.nri.org/ratzooman).

GIS

Using ArcView 3.1 (ESRI, Redland, CA, USA), rodent trapping sites and locations of disease hotspots were mapped in relation to a variety of data layers supplied by the eThekwini (Durban) Municipality: geology, streets, rivers, land use, and aerial photographs.

RESULTS

Rodent species composition and distribution

Out of the total of 262 rodents, *Rattus norvegicus* comprised by far the majority (91.2% of captures), and *Mus domesticus* comprised 4.6% of captures. Other rodent species collected were *Rattus rattus* (*n* = 6), *R. tanezumi* (*n* = 2), *Tatera brantsii* (*n* = 2) and *Mastomys natalensis* (*n* = 1)(Table 1). *Rattus norvegicus* was widespread throughout the city (Fig. 2a). Although *Rattus rattus* is known to occupy roofs in suburban houses in Durban, it was apparently once much more widely distributed throughout the city than it is now. Anecdotal observations by long-serving vector control staff (M. Hayter, personal communication) reveal a steady decline in the numbers of *R. rattus* caught in traps relative to *R. norvegicus*. We found no *R. rattus* at all in the commercial, industrial and residential (formal and informal) samples; in this study, black rats were collected only from a wildlife rehabilitation sanctuary in the small town of Umkomaas (50 km south of Durban Harbour; Fig. 2a). The two *R. tanezumi* specimens were collected from a small poultry farm in a semi-rural area of small holdings near the western border of the municipal region. Although thought to be restricted to South-East Asia (Musser & Carleton 2005), recent data shows that this species occurs widely in South Africa, where it is often sympatric with *R. rattus*. The species can be distinguished from *R. rattus* on chromosomal and cytochrome-*b* sequence grounds, but is not readily distinguished morphologically (Bastos *et al.*, personal communication). Two gerbils (*Tatera brantsii*) were collected from a fallow field, just outside the western

Table 1 Species composition and seroprevalence status of rodents collected from the Durban (eThekwini) municipal region of South Africa

Species	Total no. captured	No. individuals positive			
		Plague	Leptospirosis (serology)	Leptospirosis (PCR)	Toxoplasmosis
Rattus norvegicus	239	0 (180)	22(202)	8(63)	9(200)
Mus musculus	12	0(3)	0(6)	1(2)	0(4)
R. rattus	6	0(6)	0(6)	1(2)	0(6)
R. tanezumi	2	0(1)	0(2)	0(1)	0(2)
Tatera brantsii	2	0(2)	0(2)	0(0)	0(2)
Mastomys natalensis	1	0(1)	0(1)	0(1)	0(1)
TOTAL	262	193	221	69	217

Numbers in parentheses indicate the total numbers tested per species and test.

border of Durban.

Rodent zoonoses testing

No rodents tested positive for plague. Nine *R. norvegicus* were seropositive for toxoplasmosis (4.1% seroprevalence for all rodents combined), and 22 *R. norvegicus* (10.0% seroprevalence for total sample) were seropositive for leptospirosis, whereas 14.1% of rodents (eight *R. norvegicus*, one *M. musculus* and one *R. rattus*) were positive for leptospirosis using the PCR test on a smaller sample (n = 69; Table 1). The distribution of infected rats (based on serology tests) was concentrated in two major foci ("hotspots"), in the Cato Crest informal settlement (leptospirosis and toxoplasmosis: 39% and 8% seroprevalence, respectively, in a single dwelling; Fig. 2b), and the central business district of Durban (leptospirosis and toxoplasmosis: 38.0% and 12.5% seroprevalence, respectively; Figs 2,3).

In Cato Crest it was apparent that rodent densities, capture rates and infection rates were highest in transects A and B, which were situated along the Umkhombane River, and in particular in one dwelling, which was a "tuck shop" selling fresh produce (Fig. 3).

Soil conditions

Soil pH values throughout the Cato Crest settlement, both in the vicinity of houses and away from houses, were ideal for the persistence of leptospires spirochetes outside the host in damp soils throughout the informal settlement (i.e. within the spirochete's optimal tolerance range of soil and water pH levels of 7.0–8.0; Smith & Turner 1961; Table 2). Soils were usually dry, except for pools that formed around stand pipes and leaking underground pipes, along the Umkhombane River, and near drainage canals on slopes that were used for discharging waste water. Although residents no longer use the local river for washing and drinking (fresh water is supplied to all residents by means of standing pipes), children often play in the water and use the mud to construct clay animals, and are thus exposed to leptospires bacteria in water and damp soils.

Table 2 Soil pH values in Cato Manor as measured in the vicinity of houses along the transects used for the socioeconomic survey, as well as from natural soils (away from houses) of two soil types known to occur in the area

	Soil types		Transects for socioeconomic survey								
	Berea	Dwyka	A	B	C	D	E	F	G	H	I
N	3	3	3	4	2	4	2	2	3	3	2
Minimum	6.50	7.23	6.61	7.08	7.23	7.24	7.45	6.18	6.86	6.51	6.93
Maximum	7.71	7.46	7.58	7.90	7.41	7.80	7.68	6.64	7.23	7.63	8.01
Mean	7.15	7.34	7.11	7.39	7.32	7.50	7.57	6.41	7.04	7.24	7.47
Standard deviation	0.47	0.09	0.40	0.31	0.09	0.26	0.12	0.23	0.15	0.52	0.54

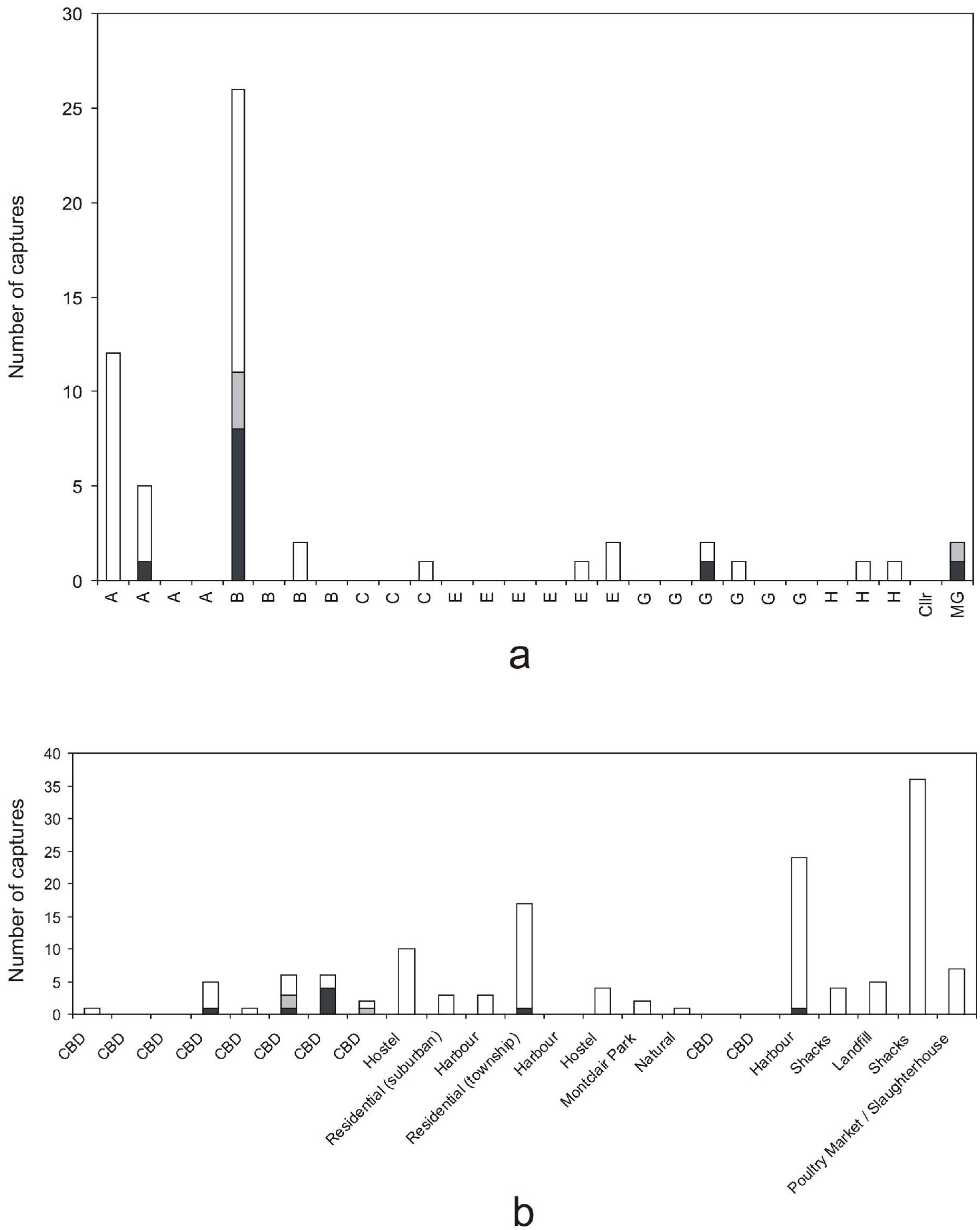

Figure 3 Frequency distribution of rodent captures, showing seronegative (white bars) and seropositive rodents for leptospirosis (black shading) and toxoplasmosis (gray shading) in (a) Cato Crest (*x*-axis labels represent transects A–I, in which individual shacks were sampled) and two outlying sites in the Manor Garden suburb (MG) and the local councillor's house near the southwestern boundary of Cato Crest (Cllr) and (b) all other sample sites. CBD, central business district.

Anthropological factors relevant to rodent-borne disease transmission

According to Janowski (2004), Cato Crest comprises some 20 000 occupants living in approximately 5000 dwellings, mostly shacks but also newly constructed electrified brick houses in Area 9, known also as Greenfields (corresponding with transects D and E used for rodent trapping). The settlement is divided into nine areas, each with an area leader. The settlement, which is close to the city center (Fig. 2a) was previously vacant and the first shacks were constructed during the early 1990s. Occupants include a mixture of local Zulu -speakers and "foreigners" (that is, other African ethnic groups). Witchcraft is prevalent, and thought to be a cause of illness. Cats and rats are seen as agents used by witches to bring curses (Janowski 2004). HIV-AIDS related illnesses and tuberculosis are highly prevalent

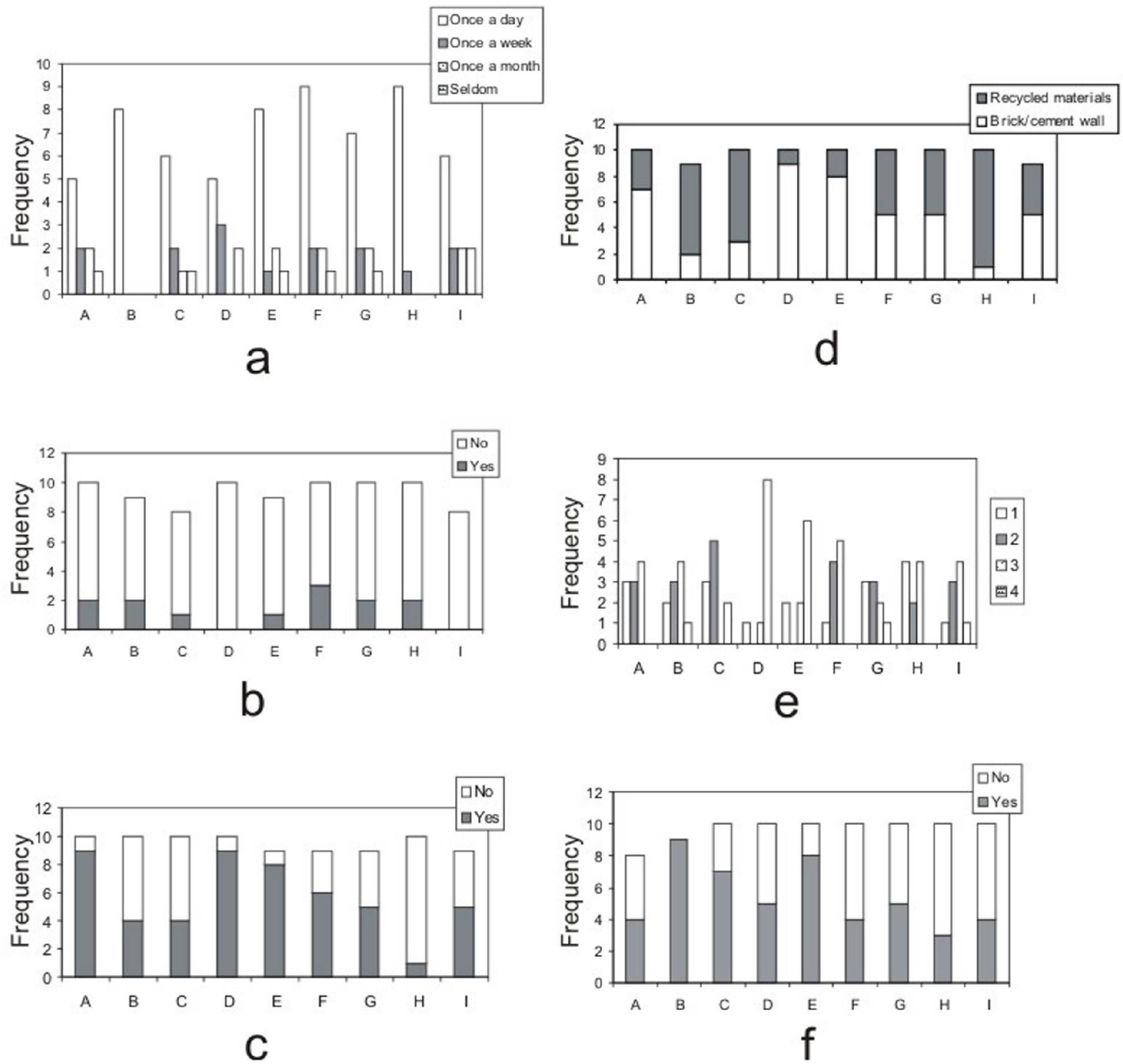

Figure 4 Responses to socioeconomic survey questions according to transect number, relating to quality of housing and prevalence, control and impacts of rodents. (a) Frequency of sightings; (b) rat bite reports; (c) use of rat poison; (d) housing construction; (e) quality of living space; (f) walls rat-proof. Transects D and E correspond to council-built brick houses, and other transects predominantly correspond to shack houses made from recycled materials.

(55% and 30%, respectively, based on patient records for the local Ekuphileni Clinic for 2002; Janowski 2004). Rats are viewed as competitors for scarce food, not as agents of disease. Residents generally expressed an aversion to eating rodents. Consumption of improperly cooked infected rodents may provide a potential mode of transmission of toxoplasmosis to humans. Semi-feral cats (the primary hosts of toxoplasmosis) are very plentiful in the settlement, where several households may share the services of a cat to help control rodents. Children cuddle and play with cats, and cats are sometimes allowed into living compounds, increasing the risk of contact with cat feces and exposure to toxoplasmosis.

Socioeconomic study

The socioeconomic report showed that mean household size in Cato Crest varied from 3.0 (transect C, $n = 10$) to 4.6 (transect I, $n = 10$). ANOVA showed that household size did not vary significantly between the nine transects ($F = 0.794$, d.f. =8, 89, $P > 0.05$). Households in the electrified, council-built housing section (transects D and E) tended to be smaller (3.1 and 3.5, respectively) than in the squatter-built housing (transects A–C and F–I; mean 4.0). However, rodents were reportedly sighted predominantly on a daily basis in all transects and there was no significant variation between transects in sighting frequency (observed $\chi^2 = 15.93$, d.f. = 24, one-tailed $P > 0.05$; Fig. 4a). Rat bites were reported in between one and three households per transect sample, with no significant variation between transects (observed $\chi^2 = 5.88$, d.f. = 8, one-tailed $P > 0.05$; Fig. 4b). However, there was significant variation (observed $\chi^2 = 15.46$, d.f. = 8, one-tailed $P = 0.05$) between transects with respect to the frequency of rodenticide use (invariably the local product "Rattex," an anticoagulant): all nine households surveyed in transect B (a hotspot for rodent disease), as opposed to between 4 and 8 households (out of 10 surveyed in each transect) in other transects (Fig. 4c).

Housing construction (brick or cement versus recycled materials; $\chi^2 = 22.46$, d.f. = 8, one-tailed $P < 0.001$), quality of living space (scored subjectively using categories 1 to 4 for poor to good; see Appendix I; $\chi^2 = 51.59$, d.f. = 24, one-tailed $P = 0.001$) and the ease of rodent access through the walls ($\chi^2 = 24.54$, d.f. = 8, one-tailed $P = 0.002$) varied significantly ($P < 0.01$) between transects, with the council-built houses (transects D and E) being of superior quality and being more rodent-proof (Fig. 4d,f). Although *R. norvegicus* were commonly caught in squatter shacks, they were never trapped in the modern brick houses, although house mice were frequently trapped in the latter. Although the electrified housing section predominantly comprised brick houses, some households had built additional adjoining shacks, and in the squatter section, not all houses were built from recycled materials, with some being constructed from brick or cement (Fig. 4d).

Human testing

A total of 217 human sera were tested for past exposure (antibody presence) to plague, leptospirosis and toxoplasmosis. The sample was made up predominantly of women ($n = 178$; 82% of sample) and adults under 35 years of age ($n = 129$; 60% of sample). No serological evidence was found for prior exposure to plague. Overall, for Cato Crest residents the seroprevalence was 19% for leptospirosis and 35% for toxoplasmosis (Fig. 5). Based on χ^2 tests, there were no significant differences between different areas (Fig. 5; leptospirosis: observed $\chi^2 = 12.02$, d.f. = 9, one-tailed $P > 0.05$; toxoplasmosis: observed $\chi^2 = 9.01$, d.f. = 9, $P > 0.05$). However, when data from Area 9 (corresponding to transects D and E; Fig. 2b), representing electrified, council-built houses, were pooled, the seroprevalence values were somewhat lower than for the total samples, that is, 13% (as opposed to 19%) and 23% (as opposed to 35%) for leptospirosis and toxoplasmosis, respectively. χ^2 tests showed no significant effect of sex on seroprevalence for leptospirosis (observed χ^2 with Yates correction = 0.01, d.f. = 1, $P > 0.05$) or toxoplasmosis (observed χ^2 with Yates correction = 0.097, d.f. = 1, $P > 0.05$). Based on χ^2 tests of seroprevalence differences between five arbitrary age classes (18–22, 22–28, 28–35, 35–42 and >42), there was no effect of age on toxoplasmosis seroprevalence (observed $\chi^2 = 2.53$, d.f. = 4, one-tailed $P > 0.05$; highest at 40% in the two youngest classes but only slightly lower at 35% in the oldest age class); however, age did have a significant effect ($P < 0.05$) on leptospirosis ($\chi^2 = 11.8$, d.f. = 4, $P = 0.02$), with seroprevalence highest (37%) in the youngest age class (18–22 years) and lower (9–21%) in the four older age classes.

DISCUSSION

Serological testing of rodents from 54 sites throughout the Durban municipal area demonstrated zero seroprevalence of plague and low overall seroprevalence values for leptospirosis (10%) and toxoplasmosis (4%). From serological testing, positive results were obtained only for the numerically dominant species, *R. norvegicus*, although a single *M. musculus* and a *R. rattus* were shown by the

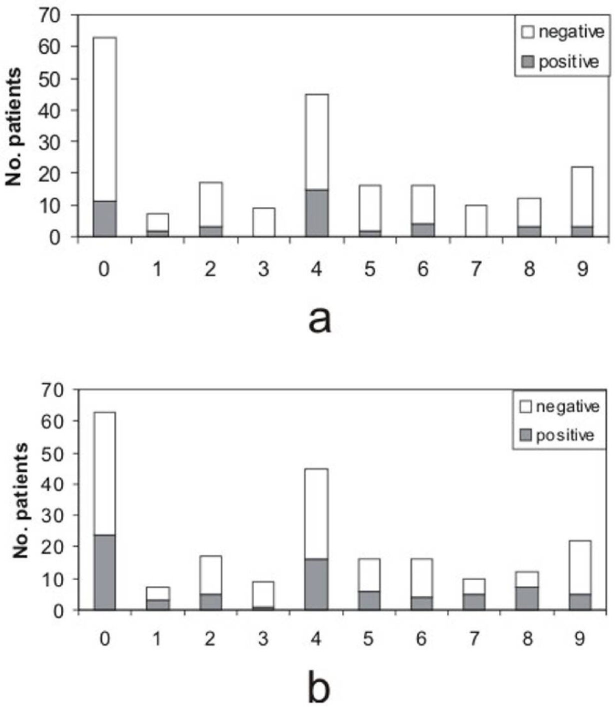

Figure 5 Distribution of seropositive human cases for (a) leptospirosis and (b) toxoplasmosis in Cato Crest according to nine recognized areas. The first category ("0") represents area unknown (i.e. where donors failed to include this information).

PCR methods to contain DNA of *Leptospira* bacteria. Although seropositive results were obtained over a wide geographical area of the municipality, seroprevalence increased significantly in two disease hotspots: in the commercial district of Durban and in one location within the Cato Crest informal settlement.

Leptospirosis and toxoplasmosis seroprevalence was concentrated in a large sample of rodents (representing very high local densities, as evidenced by numerous burrows) obtained from a tuck shop in transect B. While soil pH conditions were optimal for environmental persistence of leptospires across all transects, transect B occupied the valley bottom close to the Umkhombane River. The soil in this area was also particularly damp due to the presence of a broken water pipe (Fig. 6a). Such damp conditions, in addition to the optimal pH, would be particularly favorable for the persistence of leptospires. In addition, the presence of illegal litter dumps near the tuck shop and along the nearby river (Fig. 6c) provided adequate food and harborage to sustain high densities of brown rats. Although every attempt was made to standardize trapping effort (i.e. for each trapping session one multi-capture trap and three Sherman traps were set at each trap station), trap success was conspicuously higher in transects A and B (Fig. 3a). Although burrows were observed in the compounds of electrified modern houses in transects D and E (Area 9), and rats (and rat bites) were reported regularly in all transects (Fig. 4), *R. norvegicus* were never caught indoors in the modern houses, verifying the results of the housing quality assessments made during the socioeconomic study (Fig. 4d,f), whereby the electrified houses were of a significantly better quality and more rat-proof than the squatter shacks (Fig. 6). Nevertheless, *M. musculus* could gain access and were plentiful inside the modern houses.

Although limited evidence of infection was obtained for *M. musculus* (one positive PCR result for leptospirosis; Table 1), only 2–6 individuals of this species were tested (depending on the test employed, out of 12 captured; Table 1) and it is possible that more intensive sampling of this species will demonstrate prevalent exposure to leptospirosis and toxoplasmosis. The species is known to carry many zoonotic diseases (De Graaff 1981).

Human testing confirmed that two diseases were being spread from rats to humans: leptospirosis and toxoplasmosis. It is also possible that human infection may be occurring from secondary sources such as via dogs or in contaminated meat. Despite the clumped distribution of the two diseases in rodents, humans from all nine areas of the settlement showed no significant differences with respect to the seroprevalence of either disease. This can be easily explained by the fact that residents move widely throughout the settlement, both for social reasons and to purchase food from tuck shops, for example the contaminated food stored in the tuck shop in transect B. According to the anthropological study, children from a wide area visit the river to make clay animals from the damp soils in the affected area, which would favoring leptospirosis transmission.

Since cats may range widely (home ranges of 3.7 to 10.8 ha were obtained for six radio-collared feral cats living on the campus of the nearby University of KwaZulu-Natal, approximately 5 km from the study site; Tennant 2005), and come into close contact with humans in Cato Crest (as shown in the anthropological study), this might explain the widespread toxoplasmosis seroprevalence found in residents from throughout Cato Crest. Alternatively, or in addition, exposure to raw domestic

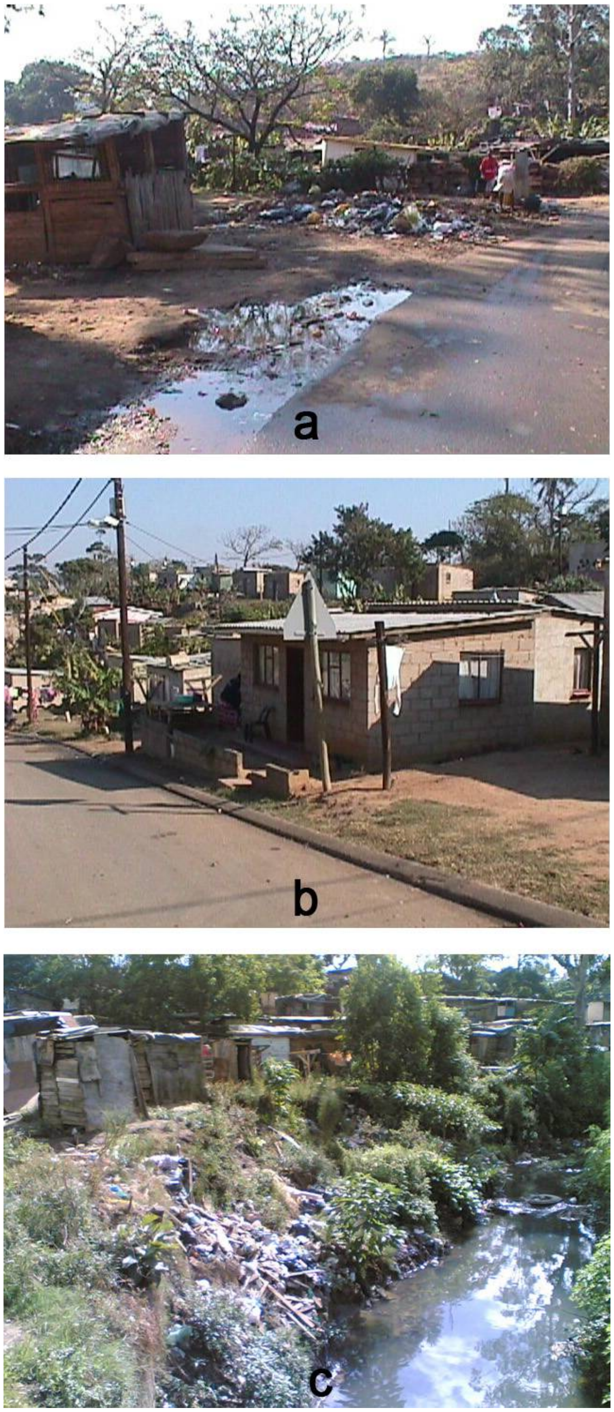

Figure 6 Environmental conditions of the Cato Crest, Durban (eThekwini), municipal region of South Africa: (a) shack near rodent hotspot in Cato Crest, (b) modern brick house in Area 9 of Cato Crest, and (c) illegal dumping site along Umkhombane River.

animal meat during meal preparation is probably important as a route of transmission.

However, the seroprevalence of the two diseases in humans was lower (albeit not significantly so) in the brick houses relative to the shacks, which may be attributable to the better socioeconomic conditions and reduced human–rodent contact due to restricted access of *R. norvegicus* (but not *M. musculus*) into modern houses.

Rural plague outbreaks were frequent in the first half of the 20th century in South Africa. Plague has been quiescent in South Africa since 1982, when the last outbreak occurred in an informal rural settlement near Port Elizabeth, Eastern Cape Province (Isaäcson 1986). Much of South Africa is ecologically suitable for plague, and the potential for urban plague outbreaks in informal settlements such as Cato Crest makes surveillance highly desirable (Govere *et al*. 1999).

Management outcomes of the project: lessons learned and application to the Boston Model

By identifying rodent disease endemic areas and their environmental and socioeconomic correlates, disease-bearing rodents can be controlled more effectively and inexpensively, as well as in an environmentally friendly manner. This “sharpshooter” approach works much better than the alternative “shotgun” approach.

Recent newspaper articles have dramatized the apparent increase in Durban’s rodent populations, often exaggerating their physical size, and thereby spreading panic. On the other hand, environmentalists have complained about so-called “indiscriminate” poisoning campaigns which may harm non-target animals. The results of the Ratzooman project (www.nri.org/ratzooman), including the findings presented here, offer a rational response to both of these valid concerns. Not only is the project involved in proactively testing rodent populations in known problem areas where rodents congregate (informal markets and settlements, hostels, the harbor and food outlets), thus allowing predictive models that will ultimately allow scientists to map high-risk areas for diseases, but the approach also guides rodent control staff to specific high-risk areas where baiting or alternative control mechanisms (e.g. trapping) can be carried out in a targeted, safe and effective manner.

Following from the dissemination of the results presented here in various local media as well as an international workshop held in South Africa from 4–5 May 2006, city officials and community representatives responded by acknowledging the problem and committing themselves to an urgent short-term plan of action. This buy-in from both officials and the local Cato Crest community was largely ensured by involving all affected parties intimately from the beginning of the project.

A committee was formed under the municipal Cato Manor Area-Based Management and funds were committed to a multi-pronged community health awareness and action campaign. Educational brochures and questionnaires (in the local isiZulu language) about personal hygiene, rodent-borne diseases and other environmental health issues were distributed to all 5000 households in the settlement. This campaign culminated in a clean-up day in Cato Crest in June 2006 involving all municipal service departments and the local community. The exercise was successful in terms of the extent of participation by both the community and municipal service providers. Following this, a year-long pilot study was initiated, employing local residents to distribute break-back rodent traps to 100 Cato Crest households at a time (moving the traps to new households on a monthly basis), teaching them to undertake intensive trapping and also to practice personal hygiene to minimize rodent contact and help to break disease transmission routes. Durban's mayor and the director of the Durban Natural Science Museum promoted the campaign on the local Zulu radio station.

The successful implementation of our research-based rodent management recommendations by municipal officials and the community was gratifying if somewhat unexpected, and begs the question as to what factors contributed to this success and what lessons can be learned. In the same way, the successful implementation of urban rodent control during the 1990 Boston road construction project led to the formulation of the Boston Model. Figure 7 shows a modified version of the Boston Model, illustrating refinements and modifications gleaned from the findings and experience at Cato Crest and more widely in the Durban area. Although some elements of the Boston Model are missing (e.g. legal code enforcement, sewer services), the same principles that contributed to the success of the Boston Model (a scientifically driven centralized approach, synergistic cooperation and communication between scientists, city officials, vector-control specialists and the community) contributed to the successful outcomes at Cato Crest.

These results demonstrate that third-world cities are not powerless to respond to seemingly overwhelming problems of rodent infestations. By forming international partnerships to obtain necessary funding and expertise, adopting an inclusive program approach, educating and involving communities and ensuring that they benefit from employment creation opportunities (selling home-made traps, field assistance, brochure distribution), and subscribing to a centralized management with significant scientific and rodent-management expertise, risks of zoonotic infections from rodents can be dramatically reduced.

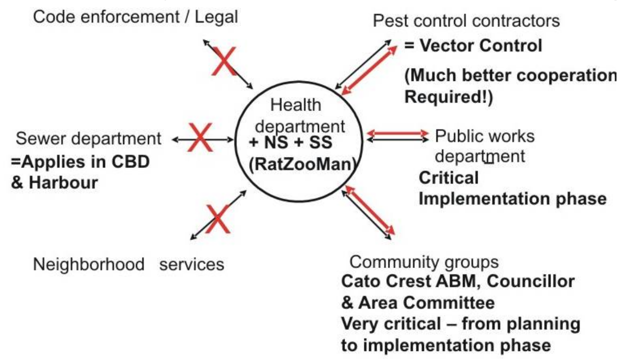

Figure 7 Revised Boston Model based on results obtained in Durban and in particular the Cato Crest informal settlement. NS, natural scientists; SS, social scientists; ABM, area base management.

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