The effect of irrigated urban agriculture on malaria, schistosomiasis and soil-transmitted helminthiasis in different settings of Côte d'Ivoire

INAUGURALDISSERTATION

zur
Erlangung der Würde eines Doktors der Philosophie

vorgelegt der
Philosophisch-Naturwissenschaftlichen Fakultät der
Universität Basel

von

Barbara Matthys

aus
Zürich (Schweiz)

Basel, 2006

Genehmigt von der Philosophisch-Naturwissenschaftlichen Fakultät auf Antrag der

Herren Prof. Dr. Marcel Tanner, Prof. Dr. Burton H. Singer und Prof. Dr. Jürg Utzinger.

Basel, den 6. Dezember 2006

Prof. Dr. Hans-Peter Hauri
Dekan

Acknowledgements

The present PhD thesis was carried out within the “National Centre of Competence in Research (NCCR) North-South” programme and a research partnership between the Swiss Tropical Institute (STI) in Basel, Switzerland, the Centre Suisse de Recherches Scientifiques (CSRS) in Adiopodoumé, and the Université de Cocody in Abidjan, Côte d’Ivoire. This work was feasible only with support and various contributions of many people and institutions in different ways.

My sincerest thanks are addressed to my supervisors at the STI, namely Prof. Marcel Tanner (Director STI), Prof. Jürg Utzinger (Project Leader, Dept. of Public Health and Epidemiology), PD Dr. Penelope Vounatsou (Project Leader, Dept. of Public Health and Epidemiology); at the Université de Cocody Abidjan to Prof. Eliézer K. N’Goran (UFR Biosciences) and at the CSRS, to Dr. Andres Tschannen (current Vice-Director). They were all responsible for the study design, and their support throughout the last three years remains invaluable. I am deeply grateful to Prof. Jürg Utzinger for his enthusiastic and stimulating drive in doing research at highest level that motivated me to give my best, but also for introducing me tactfully and patiently into the technique of writing scientific papers. I am deeply thankful to Prof. Marcel Tanner who enabled and inspired this work, for his confidence and his discrete and determined guidance that allowed me a great latitude and at the same time kept me in the right track. I wish to express my thanks to PD Dr. Penelope Vounatsou who was always ready to help me in statistics with a lot of patience. I am most grateful to Prof. Eliézer K. N’Goran for his generous support and his wise advice during the whole fieldwork. I would like to say my warmest thanks to Dr. Andres Tschannen for his agronomic expertise and particularly for his backing, encouragements and friendship during my stays in Côte d’Ivoire and after. I am very thankful to Prof. Gueladio Cissé (current Director of the CSRS) who was always very supportive at institutional level, but also for his methodological inputs and open-minded communication. My thanks are also addressed to Dr. Olivier Girardin (former director of the CSRS, 1998-2004) for his institutional support. I would also like to thank Prof. Burton H. Singer for having accepted to act as the external examiner of this PhD thesis.

My gratitudes are expressed towards the Chief Medical Doctors of the district and region of Man, Dr. Valentin Ettekou Akpa and Dr. Djah Zago for their interest in this study and for facilitating our work in Man. My special thanks are expressed to Dr. Benjamin Koudou from the CSRS for his reliable logistical and methodological assistance.

I am indebted to the laboratory technicians Mahamadou Traoré, Salia Diabaté, Laurent K. Lohourignon, Sosthène Brou, Alphonse Allangba, and Abdoulaye Fondjo for their loyal and faithful field and laboratory work of highest quality. My thanks are expressed to Mr. Koné Moussa, entomological technician at the University of Bouaké, who accompanied me as a highly committed tutor during all field surveys in Abidjan and Man. I am very thankful to the students of the Université de Cocody and the polytechnic institute of Yamoussoukro for their dedicated help in the questionnaire surveys: Francis Adiko, Hermann Comoé, Emmanuel Gbede Becket, Césaire Brou, Franck Dakouri Gbaka, Fofana Diakaridja and Naphirema Koné. My thanks go also to Olivier Anouman, Ousmane and Adama Konaté and Liliane Zahoui for data entry and laboratory assistance.

I would like to express my sincere gratitude to Mr. Denis Doua (Director of the NGO ODAFEM in Man) who was very interested in this study and placed a highly motivated team at my disposal during the whole period of field work. Sincere thanks to Samuel Tokpa, Maurice Kpan, Christian Gueu Sadia, Raoul Dion, Pauline Blé Gosamé, Alice Thian Yoahan, and Sylvie Sadia for their wonderful commitment in helping to organise and conduct the different surveys.

I am deeply indebted to the farmers delegates and to Ms Vieira (ANADER Abidjan), and particularly to all farming and non-farming families from Abidjan and Man who participated in this study and dedicated their precious time. The underlying knowledge of this work would not have been possible without their straightforward collaboration. My thanks are also addressed to all chiefs of the neighbourhoods, school directors of the primary schools and communal youth associations in the respective neighbourhoods for placing rooms and other infrastructure at our disposal during the parasitological and the questionnaire surveys.

At STI level, I am very grateful to Margrit Slaoui, Christine Walliser and Eliane Ghilardi, Isabelle Bolliger as well as Ulrich Wasser and his team for their strong administrative support. My thanks are also addressed to Prof. Mitchell Weiss, Head of the Department of Public Health and Epidemiology, for support at departmental level. Elisabeth Escher provided material for the CSRS laboratory – many thanks! I would also like to thank Yvette Endriss for her excellent cooking service.

I greatly appreciated the valuably assistance of Dr. Giovanna Raso, Laura Gosoniu, Stefanie Granado and Peter Steinmann in different ways.

Many thanks to all senior scientists and PhD fellows who contributed to this work in one way or another: at CSRS, and NCCR South (Cinthia Acka, Norbert Thian-Bi, Dieudonné Silué, Koné Brama, Dr. Dongo Kouassi, Cléopatre Kablan, Mohamed Doumbia, Dr. Koné Blaise, Dr. Alain Betsi and Dr. Alain Kouadio) and NCCR North (PD Dr. Jakob Zinsstag, PD Dr. Brigitte Obrist, PD Dr. Kaspar Weiss, Patricia Schwärzler, Dr. Esther Schelling, Dr. Markus Hilty, Stefan Dongus, and Daniel Weibel), and at STI (Tobias Erlanger, Marlies Craig, Musa Mabaso, Nina Schild and Alena Gsell).

I acknowledge financial support from the (NCCR) North-South programme entitled "Research partnerships for mitigating syndromes of global change", Work Package 3 (WP3) entitled "Health and environmental sanitation"; the Swiss National Foundation through an SNF-Förderungsprofessur to Dr. J. Utzinger (project no. PPOOB-102883); the Swiss Development Cooperation (SDC) through its project at the CSRS "Contribution to the process of national reconciliation in Côte d'Ivoire"; and the "Basler Dissertationenfonds" from the "Basler Studienstiftung" for their financial contribution to the document printing costs of this thesis booklet.

Summary

Malaria is responsible for more than one million deaths every year, mainly children under the age of five years living in sub-Saharan Africa. At least one billion people harbor one or several of the three main soil-transmitted helminths, namely *Ascaris lumbricoides*, hookworms and *Trichuris trichiura*, and about 207 million people are infected with schistosomes. An estimated 70,000 people die each year from amoebiasis, caused by *Entamoeba histolytica*. Giardiasis, caused by *Giardia duodenalis*, is responsible for 2.8 million annual infections. Poor rural and urban communities in developing countries bear the highest burden of the above-mentioned diseases. Their causes are multifactorial including lack of access to clean water, improved sanitation and health services, as well as inadequate treatment, protection and prevention.

The highest rates of urbanization currently occur in the less developed regions of Africa and Asia, and it is predicted that the majority of the population will be living in small and medium urban centers in the near future. The maintenance of traditional livelihoods, including agriculture, is a typical feature in urban settings across Africa, especially in small towns where population densities and land pressure are lower than in big cities. Urban agriculture contributes to food security and livelihood opportunities for poor urban dwellers. However, the adaptation of disease vectors and intermediate hosts to urban ecosystems has been observed, which might further enhance the negative effects associated with persistent rural lifestyles. For example, the creation of malaria vector breeding sites and contact with contaminated water and soil in areas of irrigated agriculture may increase the transmission of vector-borne, water-related and soil-transmitted parasitic diseases.

This PhD focused on the interface of agriculture and human health in two different urban settings of Côte d'Ivoire. The overarching goal was to contribute to a better understanding of the effects of irrigated urban agriculture on the transmission of malaria, schistosomiasis, soil-transmitted helminthiasis and intestinal protozoan infections. The research entailed a considerable amount of fieldwork, carried out between April 2004 and July 2005. In a first step, six zones of irrigated agricultural land use were identified both in Abidjan, the economic capital of Côte d'Ivoire (3.3 million inhabitants), and in the medium-sized town of Man (115,000 inhabitants) in the western part of the country. Next, two standardized mosquito breeding site assessments were conducted in these agricultural zones in the rainy season (September 2004) and in the dry season (February 2005). In each urban setting, a minimum of 120 farming households and additionally 30 non-farming households were randomly selected. Geographic coordinates of houses and the main agricultural plots were recorded. Name, age and sex of all household members were registered. In October 2004, interviews on agricultural land use, farming practices and water storage were conducted with the heads of the farming households. In a cross-sectional survey done in May/June 2005, questionnaires were administered to all households to assess the socio-economic status, sanitary facilities and common water contact patterns. From each study participant, a finger prick blood sample and a stool sample were collected. Thick and thin blood films were stained with Giemsa and examined for *Plasmodium* spp. under a light microscopy. The stool samples were prepared based on the Kato-Katz technique and eggs of *Schistosoma mansoni*, *A. lumbricoides*, hookworm and *T. trichiura* were recorded separately. Cysts or trophozoites of intestinal protozoa, including *Entamoeba histolytica/E. dispar* and *G. duodenalis* were identified using an ether-formalin concentration method. Risk factors were identified by fitting multivariate non-random and random effects Bayesian regression models integrating spatial correlation of infection.

Agricultural land use in Abidjan was characterized by market gardens on lagoon shores and high-yield vegetable production. The vegetable production areas in Abidjan developed as a consequence of land access difficulties in unexploited public and private areas near poor settlements, mainly at lagoon shores. In Man, farming was family- and subsistence-based. Predominant agricultural activities were traditional irrigated rice farming and vegetable production in lowlands and along the Kô River.

The typical demographic and socio-economic profile of a vegetable producer in Abidjan is that he is an immigrant from Burkina Faso, illiterate and lacking a professional agricultural training. Malaria and intestinal parasitic infections were most prevalent among the final study cohort of 370 farmers and family members from 121 farming households. We found overall prevalences of *T. trichiura*, *P. falciparum* and hookworm of 42.6%, 24.3% and 17.3%, respectively. The parasites were heterogeneously distributed between the six market garden zones. Prior health issues were suppressed by the farmers with the daily livelihood struggle and reported symptoms due to intestinal parasitic infections were of less importance when compared to malaria. In-depth focus group discussions revealed that the working environment was discerned as unhealthy, and waste dumps and human defecation grounds were perceived as main health risks. Farmer communities and their network are indicative for the degree of social coherence and stability in a vegetable production area because these zones are characterized by highly dynamic land use patterns.

In the town of Man, *Anopheles* larvae were present in 50.7% and 42.4% of 369 and 589 examined potential mosquito breeding sites in the rainy and in the dry season, respectively. The most productive habitats were man-made, i.e. agricultural trenches, irrigation wells, and flooded and recently transplanted rice plots. The overall prevalence of *P. falciparum* infections in the final study cohort of 574 individuals from 112 farming households was 32.1%. Risk factors for *P. falciparum* in children <15 years of age included living in specific agricultural zones (i.e. traditional irrigated rice plots, mixed crops and a large rice perimeter), proximity to permanent man-made ponds and fish ponds, periodic stays overnight in farm huts and low socio-economic status.

The final study cohort for *S. mansoni* and soil-transmitted helminthiasis comprised 586 individuals from 113 farming households. The overall prevalences of *S. mansoni*, hookworm, *E. histolytica/E. dispar* and *G. duodenalis* were 51.4%, 24.7%, 20.2% and 6.3%, respectively. Members from farming households harbored significantly more often an infection with *E. histolytica/E. dispar* and *G. duodenalis* when compared to non-farming households. Predictors for an *S. mansoni* infection included close proximity to the Kô River, contact with irrigation wells and ponds on the agricultural plots and low educational attainment. Risk factors for hookworm infection comprised living in agricultural zones of traditional smallholder irrigated rice plots and a large rice perimeter, using water from domestic wells and low socio-economic status. Infection prevalences of *P. falciparum*, *S. mansoni* and hookworm were spatially highly heterogeneous between the agricultural zones and highest infections occurred in a zone of a large rice perimeter. *P. falciparum* infection intensity and hookworm infection prevalence were best explained by spatial random effect models. Spatial correlation between farmers' houses was not significant.

The findings of the present work illustrated a clear picture of the interconnections between specific irrigated agricultural land use and agricultural activities, and malaria and intestinal parasitic infections in different urban settings of Côte d'Ivoire. The outcomes lead to an enhanced understanding of their epidemiology in local agro-ecological urban settings and related contextual determinants (i.e. agricultural, behavioural, demographic, socio-economic and environmental factors) and allows the design of readily adapted prevention and control interventions (e.g. tangible vector control strategies and prevention measures for helminth infections) which actively involve farming communities in the subsequent implementation and control management.

Zusammenfassung

Malaria ist verantwortlich für über eine Million Todesfälle pro Jahr, hauptsächlich bei Kindern unter fünf Jahren. Mehr als eine Milliarde Menschen sind mit mindestens einem der häufigsten Nematoden Spulwurm (*Ascaris lumbricoides*), Hakenwürmern oder dem Peitschenwurm (*Trichuris trichiura*) infiziert, und 207 Millionen Menschen mit *Schistosoma* ssp., dem Erreger der Bilharziose. Rund 70'000 Menschen sterben jährlich an Amöbiasis, verursacht durch *Entamoeba histolytica*. Giardiasis, welche durch *Giardia duodenalis* hervorgerufen wird, ist verantwortlich für 2.8 Millionen Infektionen pro Jahr. Die Bevölkerung armer Gebiete in Entwicklungsländern trägt die höchste Last dieser humanparasitären Krankheiten. Die Ursachen sind vielschichtig; zu den Hauptfaktoren zählen Mangel an Zugang zu sauberem Wasser, sanitären Einrichtungen und Gesundheitsdiensten, sowie inadäquate Behandlung, Schutz und Prävention.

Asien und Afrika verzeichnen zurzeit die höchsten Urbanisierungsraten und es wird vorausgesagt, dass in naher Zukunft die Mehrheit der Bevölkerung dieser Regionen in kleinen und mittelgrossen Städten leben wird. Städtische Landwirtschaft ist in Afrika weit verbreitet, insbesondere in weniger dicht besiedelten Kleinstädten. Einerseits leistet die städtische Landwirtschaft einen wichtigen Beitrag zur Ernährung und zum Lebensunterhalt der ärmeren Stadtbevölkerung. Andererseits bestehen jedoch Hinweise, dass sich Krankheitsüberträger und Zwischenwirte an städtische Ökosysteme adaptieren. Diese Anpassungen, kombiniert mit ländlichen Lebensgewohnheiten, könnten negative Auswirkungen auf die Gesundheit der städtischen Bevölkerung haben. Die Bewässerungslandwirtschaft in Städten stellt ein erhöhtes Risiko für die Übertragung von humanparasitären Krankheiten dar, zum Beispiel durch vermehrt auftretende Brutstätten von *Anopheles* Mücken (Überträgerin der Malaria) und durch intensiveren Kontakt der Bauern mit verunreinigtem Wasser und Boden.

Die vorliegende Arbeit ist im Schnittbereich von Landwirtschaft und Gesundheit angesiedelt und befasst sich mit zwei unterschiedlichen städtischen Kontexten in Côte d'Ivoire, Westafrika. Das Ziel war, die Auswirkungen von Bewässerungslandwirtschaft auf die Übertragung von Malaria, Schistosomose (Bilharziose) und anderen humanparasitären Krankheiten besser zu verstehen. Die Untersuchungen bestanden aus einem grossen Teil Feldarbeit, die zwischen April 2004 und Juli 2005 durchgeführt wurde. In einem ersten Schritt wurden in Abidjan (grösste Stadt der Côte d'Ivoire, 3.3 Millionen Einwohner) und in der mittelgrossen Stadt Man (Provinzhauptort mit ca. 115'000 Einwohnern) im Westen des Landes je sechs Zonen mit bewässerter Landwirtschaft ausgewählt. Als Nächstes wurden in

diesen Zonen in der Regenzeit im September 2004 und in der Trockenzeit im Februar 2005 je eine Erhebung der *Anopheles* Brutstätten durchgeführt. In beiden Städten wurden 120 landwirtschaftsbetreibende und zusätzlich 30 nicht-landwirtschaftsbetreibende Haushalte zufällig ausgewählt. Die geographischen Koordinaten der Häuser und der Felder wurden registriert, und Name, Alter und Geschlecht aller im Haushalt lebenden Personen erfasst. Im Oktober 2004 wurden die landwirtschaftsbetreibenden Haushalte über Landnutzung, landwirtschaftliche Praktiken und Wassernutzung befragt und im Mai und Juni 2005 fand eine Befragung in allen Haushalten über sozioökonomische Eigenschaften, sanitäre Einrichtungen und Wasserkontakt statt. Von jedem Studienteilnehmer wurde ein Bluttropfen zur Herstellung von dicken und dünnen Blutausstrichen und eine Stuhlprobe gesammelt. Die mit Giemsa eingefärbten Blutausstriche wurden unter einem Lichtmikroskop auf *Plasmodium* untersucht. Die Stuhlproben wurden anhand der Kato-Katz Methode präpariert und Eier von *Schistosoma mansoni*, *A. lumbricoides*, Hakenwürmern und *T. trichiura* wurden notiert. Die Darmprotozoen, zum Beispiel *Entamoeba histolytica/E. dispar* und *G. duodenalis*, wurden mittels der Formalin-Konzentrationsmethode nachgewiesen. Anhand von Bayesischen Regressionsmodellen, bei welchen die räumliche Korrelation von Infektionen eingebaut werden kann, wurden Risikofaktoren ermittelt.

Die landwirtschaftliche Nutzung in Abidjan ist durch Gemüseanbau in Marktgärten in Uferzonen der Lagune charakterisiert. Die Landwirtschaft in Man ist hauptsächlich auf Eigenbedarf ausgerichtet und der Anbau von traditionellem Reis und Gemüse in Niederungen und entlang des Flusses Kô sind vorherrschend. Der typische städtische Bauer in Abidjan ist Zuwanderer, hauptsächlich aus Burkina Faso, um 40 Jahre alt, und Gemüseanbauer. Vier von fünf Bauern sind des Lesens und Schreibens unkundig und praktisch keiner verfügt über eine landwirtschaftliche Ausbildung. Infektionen mit Peitschenwurm, Hakenwurm und *P. falciparum* (Erreger der Malaria) traten unter 370 Personen aus 121 landwirtschaftlichen Haushalten zu 42.6%, 17.3% und 24.3% auf. Die Prävalenzen dieser Parasiten waren ausgesprochen heterogen zwischen den landwirtschaftlichen Zonen verteilt. Krankheitssymptome, welche auf Darmparasiten zurückzuführen sind, wurden von den Bauern nicht oft erwähnt verglichen mit Malaria, und Gesundheitsprobleme wurden durch alltägliche Probleme verdrängt. Gruppendiskussionen ergaben jedoch, dass die Umwelt als gesundheitsschädlich wahrgenommen wurde. Vor allem Hausmülldeponien und Stellen mit menschlichen Fäkalien wurden als Gesundheitsrisiken eingestuft. Vereinigungen von Gemüseanbauern in einzelnen Zonen sowie das soziale Geflecht der Bauern untereinander wurden als „soziales Kapital" erkannt. Beide Netzwerke widerspiegeln den Grad des

Zusammenhaltes und somit die Stabilität einer landwirtschaftlichen Zone hinsichtlich Landdruck und Landnutzungsdynamik.

Von insgesamt 369 in der Regenzeit und 589 in der Trockenzeit untersuchten potentiellen *Anopheles* Brutstätten in der Stadt Man wurden in 50.7% und 42.4% *Anopheles* Larven entdeckt. Mit Wasser gefüllte Furchen zwischen Gemüsebeeten, landwirtschaftliche Bewässerungsbrunnen sowie überflutete oder kürzlich bepflanzte Reisfelder erwiesen sich als die produktivsten Habitate für *Anopheles* Larven. Ein Drittel (32.1%) aller 574 Studienteilnehmer aus 112 landwirtschaftlichen Haushalten mit vollständigen Daten waren mit *P. falciparum* infiziert. Risikofaktoren für *P. falciparum* Infektionen bei Kindern unter 15 Jahren waren das Wohnen in landwirtschaftlichen Zonen mit traditionell bewässerten Reisfeldern, gemischten Kulturen und grossflächig bewässerten Reisfeldern, das Wohnen in der Nähe von Fischteichen und künstlichen Teichen, regelmässige Übernachtungen in Feldhütten sowie niedriger sozioökonomischer Status.

S. mansoni, Hakenwürmer, *E. histolytica/E. dispar* und *G. duodenalis* unter 586 Personen aus 113 Haushalten mit vollständigen Daten wiesen Prävalenzen von 51.4%, 24.7%, 20.2% und 6.3% auf. Landwirtschaftsbetreibende Haushalte waren deutlich häufiger mit *E. histolytica/E. dispar* und *G. duodenalis* infiziert verglichen mit nicht-landwirtschaftsbetreibenden Haushalten. Risikofaktoren für *S. mansoni* Infektionen beinhalteten die Distanz zum Kô Fluss, Kontakt mit landwirtschaftlichen Bewässerungsbrunnen, sowie eine niedrige Schulbildung. Die Nähe von landwirtschaftlichen Zonen mit traditionell und grossflächig bewässerten Reisfeldern, der Gebrauch von Wasser aus Ziehbrunnen im Hof, und ein niedriger sozioökonomischer Status waren Risikofaktoren für Hakenwürmer. Die Prävalenzen von *P. falciparum*-, *S. mansoni*- und Hakenwurminfektionen waren zwischen den landwirtschaftlichen Zonen sehr heterogen und vor allem auf eine Zone mit grossflächigen Reisfeldern konzentriert. *P. falciparum*- und Hakenwurminfektionen konnten am besten mit räumlichen Modellen erklärt werden.

Die vorliegende Arbeit zeigt ein präzises Bild der Zusammenhänge zwischen spezifischen städtischen landwirtschaftlichen Landnutzungsmustern, landwirtschaftlichen Praktiken, Malaria und Wurmerkrankungen auf. Der städtischen Landwirtschaft kommt eine zentrale Rolle bei der Bekämpfung und Kontrolle dieser Krankheiten zu und sie sollte deshalb vermehrt in Kontrollprojekte eingebunden werden. Dieses Ziel kann nur mit Hilfe einer multi-sektoriellen Zusammenarbeit im Gesundheits- und Landwirtschaftsbereich auf allen Ebenen erreicht werden.

Figures and Tables

Figures

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1. Introduction

1.1 Epidemiology of malaria, schistosomiasis, soil-transmitted helminthiasis and intestinal protozoan infections

1.1.1 Malaria

Malaria is the most important vector-borne parasitic disease worldwide. The causative agent is a one-cell parasite (*Plasmodium*), which is transmitted through the bite of a female *Anopheles* mosquito. There are four species of *Plasmodium* causing human malaria with distinct features in their life cycles and geographic distribution. *P. falciparum* occurs predominantly in sub-Saharan Africa and is responsible for the bulk of mortality and burden due to malaria. *P. vivax* is the second most important species, and its occurrence is particularly prominent in Asia. The other two species are *P. malariae* and *P. ovale*.

Figure 1.1 shows the life cycle of malaria. The malaria parasite (sporozoite) is inoculated into the human host during a blood meal of an infected female *Anopheles* mosquito. After undergoing various complex parasitic stages in the liver to evade the human immune system, the parasite multiplies asexually in erythrocytes and reinfects red blood cells. At this stage, clinical symptoms begin to manifest. A few parasites that evolved apart into sexual erythrocytic stages (gametocytes) are ingested by another *Anopheles* mosquito during a subsequent blood meal. In the mosquito's stomach, the micro- and macrogametocytes undergo another complex various-staged development. Finally, ruptured ooysts release sporozoites which move to the mosquito's salivary glands to be inoculated again into the human host (White 2003).

Recent estimates suggest that 515 million episodes of clinical malaria occurred in 2002 (95% confidence interval: 300-660 million) (Snow *et al.* 2005) and that malaria causes between 1 and 3 million deaths every year (Guinovart *et al.* 2006). Estimates of the disability adjusted life years (DALYs) lost due to malaria vary from 40.0 to 46.5 millions (Lopez & Mathers 2006; WHO 2003). More than 80% of the mortality and burden of malaria are concentrated in sub-Saharan Africa, particularly in children below the age of five years (WHO & UNICEF 2003). Malaria impedes economic growth, and hence it is closely linked with conditions of poverty. The annual loss of economic growth in malaria-endemic countries due to the disease has been estimated at 0.25-1.2% (McCarthy *et al.* 2000; Sachs & Malaney 2002). New research has shown that at the household level, the vulnerability of the poorest is increased by socio-economic differences in access to malaria interventions (Worrall *et al.* 2005).

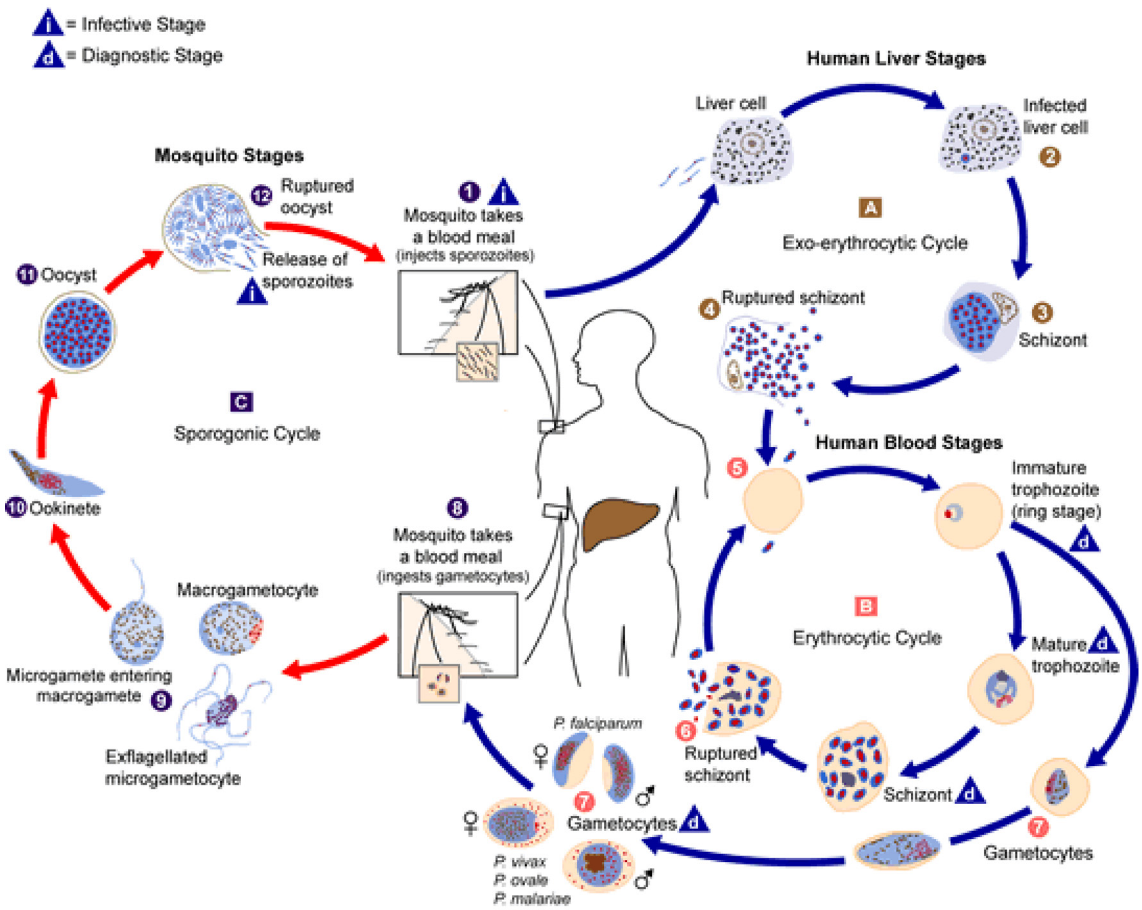


Figure 1.1 Life cycle of *P. falciparum* malaria (source: CDC)

Efforts are underway to reduce the burden of malaria. For example, the Roll Back Malaria (RBM) initiative, launched in 1998, aims at halving the global burden of malaria by 2010 by means of equitable, effective and low-cost interventions, such as the promotion of insecticide-treated nets (ITNs), and improved access to efficacious anti-malarial drugs, targeting specifically the most vulnerable groups (Binka & Akweongo 2006; Guinovart *et al.* 2006; Schellenberg *et al.* 2006; WHO *et al.* 2001)

1.1.2 Schistosomiasis

Human schistosomiasis signifies a complex of parasitic infections that are caused by a trematode blood fluke of the genus *Schistosoma* (Davis 2003). Specific aquatic or amphibious snails act as intermediate hosts. The three most important schistosome species parasitizing humans are *S. haematobium*, *S. japonicum* and *S. mansoni*. Both *S. mansoni* and *S. haematobium* occur in the Middle East and in Africa, with *S. mansoni* additionally found in different areas of South America and the Caribbean. The geographic distribution of

S. japonicum is currently restricted to the Far East, namely China, Indonesia and the Philippines. The three main human schistosome species cause different pathologies. Chronic infections with

S. mansoni and *S. japonicum* lead to intestinal schistosomiasis, whereas *S. haematobium* causes urinary schistosomiasis.

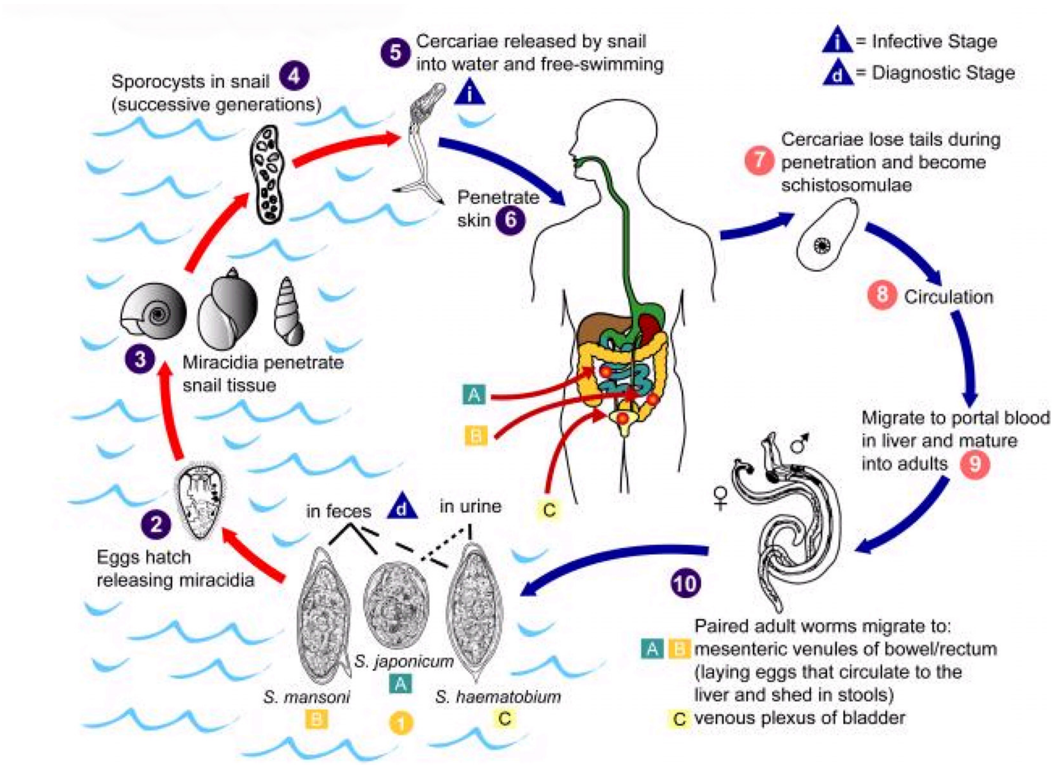


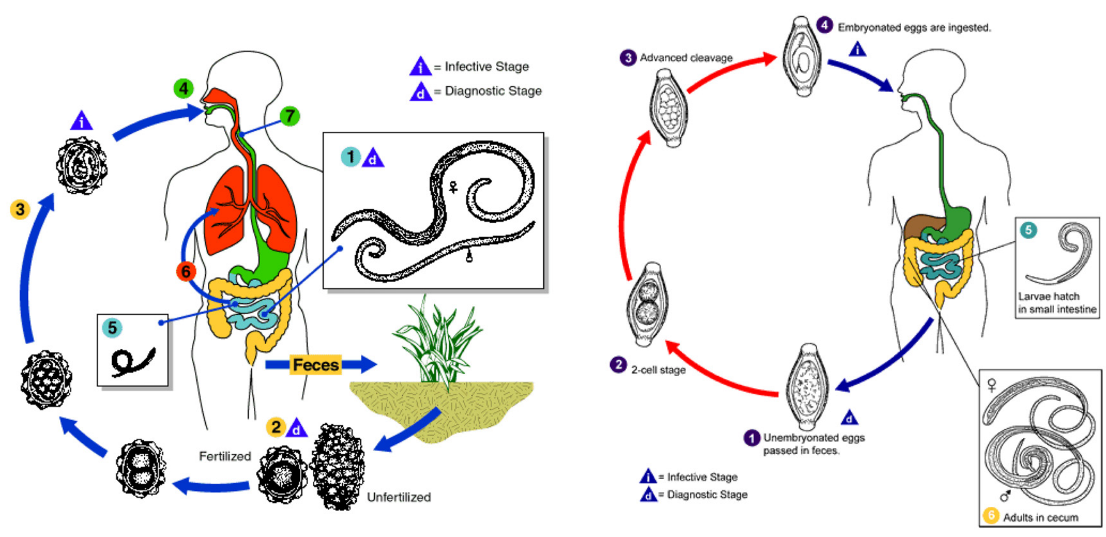
Figure 1.2 Life cycle of schistosomiasis (source: CDC)

Figure 1.2 shows the life cycle of schistosomiasis. In brief, transmission occurs when humans contact freshwater sources that have been contaminated with human faeces or urine that contained *Schistosoma* eggs. These eggs hatch and release larvae (miracidia) which penetrate the intermediate snail host. Within the snail, the miracidia multiply in two cycles and produce cercariae. The infective cercariae are released by the snails and they are free-swimming. They can penetrate the skin of an immersed human host. As soon as the cercariae have penetrated the human skin, they transform into schistosomula and migrate via the heart and then the lungs to blood vessels lining the bladder or rectum. One part of the eggs is eliminated by faeces (*S. mansoni* and *S. japonicum*) or urine (*S. haematobium*), the other part is trapped in tissues. Eggs, which migrate through the intestinal wall, cause chronic inflammation, pseudopolyposis and bleeding that are typical for intestinal schistosomiasis. Eggs stuck around the portal veins of the liver cause splenomegaly, mainly in children. Chronic hepatic schistosomiasis occludes the portal veins, resulting in hypertension (Gryseels *et al.* 2006). Re-infection results from contact with infested freshwater, because schistosomes do not replicate in humans. At highest risk of infection are children between 6 and 15 years (swimming or bathing), and people whose occupations are water-related (e.g. woman during domestic work, fishermen and farmers practising irrigated agriculture) (Davis 2003).

Recent estimates suggest that 779 million are at risk of schistosomiasis, and 207 million people are infected, primarily in sub-Saharan Africa (Steinmann *et al.* 2006). The global burden due to schistosomiasis is between 1.7 and 4.5 million disability-adjusted life years (DALYs) (Utzinger & Keiser 2004). The "true" burden of schistosomiasis, however, might be considerably higher (King *et al.* 2005). The annual mortality rate might exceed 200,000 in Africa alone, mainly due to bladder cancer or renal failure caused by urinary schistosomiasis, and liver fibrosis and portal hypertension caused by intestinal schistosomiasis (van der Werf *et al.* 2003).

1.1.3 Soil-transmitted helminthiasis

Soil-transmitted helminths are intestinal nematodes which develop partly in the soil and partly in the human body. The main species include the hookworms (*Ancylostoma duodenale* and *Necator americanus*), roundworm (*Ascaris lumbricoides*) and whipworm (*Trichuris trichiura*), and can be distinguished according to their life cycles.



Ascaris life cycle   Trichuris life cycle

Figure 1.3 Life cycle of *A. lumbricoides* and *T. trichiura* (source: CDC)

The life cycles of *A. lumbricoides* and *T. trichiura* are shown in Figure 1.3 and that of hookworm in Figure 1.4. Eggs of *A. lumbricoides* are passed via stool and go through a period of development in the soil. They are ingested via contaminated food and hatch in the human host. Released larvae re-enter the intestine via the respiratory tract and mature. Released eggs of *T. trichiura* are passed on in a direct way either by the faecal-oral route or via the soil without a development period. Hookworm eggs, after they are passed via stool to the soil, develop there into different larval stages. The L_3 stage is infective for humans; they penetrate the skin and migrate via the respiratory tract to the small intestine, where they mature into the adult stage (see Figure 1.4). Hookworms attach to the intestinal wall, where they draw blood and hence contribute to anaemia (Gilles 2003).

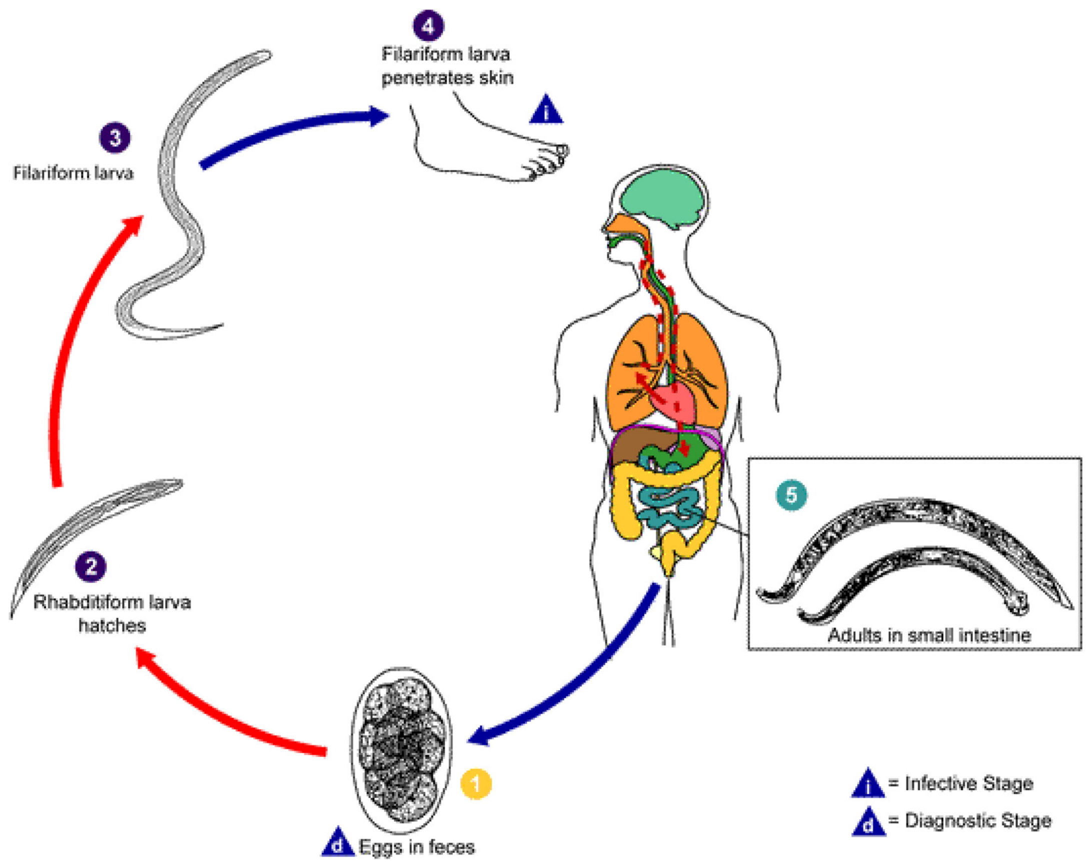


Figure 1.4 Life cycle of hookworm (source: CDC)

A. lumbricoides and *T. trichiura* occur around the world with highest prevalence found in tropical and subtropical regions and areas with inadequate sanitation (de Silva *et al.* 2003). Hookworm infections occur in tropical and subtropical regions and transmission is highest in areas with moist and sandy soils (Gilles 2003; Hotez *et al.* 2004). It has been estimated that 4.5 million people are at risk of soil-transmitted helminthiasis (Horton 2003). The latest available statistics suggest that between 807 and 1,1221 million people are infected with *A. lumbricoides*, 604-795 with *T. trichiura* and 576-795 million with hookworms (Bethony *et al.* 2006). An estimated 300 million people suffer from resulting impairments, e.g. irreversible organ damage. Clinical manifestations caused by helminthic infections are iron-deficiency anaemia and chronic intestinal blood loss, delay in physical growth and intellectual development and reduced working capacity (Horton 2003; Hotez *et al.* 2004).

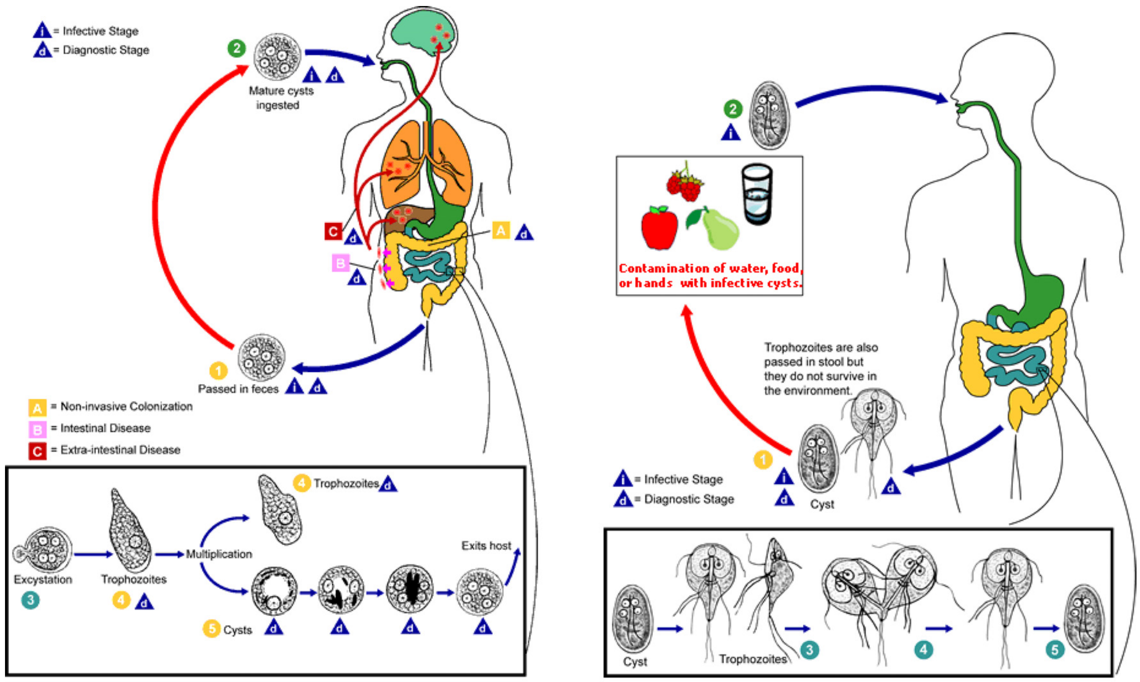
1.1.4 Control of schistosomiasis and soil-transmitted helminthiasis

In high-burden areas, the recommended strategy for the control of schistosomiasis and soil-transmitted helminthiasis is morbidity control, facilitated by the administration of antihelminthic drugs. Drugs need to be administered regularly to high-risk groups i.e. school-aged children (WHO 2002). The goal is to reduce the number of infected people harbouring high worm loads by systematic large-scale treatments in endemic areas (Bethony *et al.* 2006). An efficient channel of regular de-worming is the school system (Hotez *et al.* 2006; WHO 2002; 2005). National schistosomiasis and soil-transmitted helminthiasis control programmes have been launched in several countries of West Africa (Garba *et al.* 2006), and in East Africa (Kabatereine *et al.* 2006). In view of chemotherapy serving as the backbone of morbidity control of schistosomiasis and soil-transmitted helminthiasis and mounting drug pressure, the development of novel antihelminthic drugs is a pressing public health issue (Horton 2003; Utzinger & Keiser 2004). Chemotherapy, however fails to address the root causes of infection and reinfection of schistosomiasis and soil-transmitted helminthiasis. Hence, improved water supply and sanitation, together with health education, are the key strategies to reach sustainable reductions of these parasite infections (Utzinger *et al.* 2003).

1.1.5 Intestinal protozoa

The intestinal protozoa *Entamoeba histolytica* and *Giardia duodenalis* are the causative agents of amoebiasis and giardiasis, respectively. They occur worldwide and constitute a considerable public health burden in countries with low socio-economic conditions where there are inadequate barriers between human faeces and food and water.

The life cycles of *E. histolytica* and *G. duodenalis* are depicted in Figure 1.5. Humans are the only natural hosts of *E. histolytica*. Cysts and trophozoites are passed in faeces and ingested from contaminated food, water or hands. After excystation in the small intestine, released trophozoites migrate to the large intestine where they multiply and produce cysts that are passed in the faeces. Cysts of *G. duodenalis* that occur in contaminated water and food, are ingested by drinking, eating, or via the faecal-oral route. After passing to the small intestine, they move to the colon where they encyst again and are released with the faeces.



Amoebiasis life cycle

Giardiasis life cycle

Figure 1.5 Life cycle of *E. histolytica* and *G. doudenalis* (source: CDC)

Responsible for transmission of both protozoa are the resistant cysts in the external environment. Infants and children are at highest risk of infection. *E. histolytica* affects an estimated 480 million people worldwide (WHO 1997), causing severe tissue damage, mostly of the intestinal mucosa and in the liver, and is responsible for the annual death of 40,000-100,000 people (Stanley 2003). *G. duodenalis* is estimated to be responsible for 2.8 million annual infections in humans and contributes to nutritional deficiencies in children. Prevalence rates can reach 20-30% in developing countries. There is a need to estimate the global burden of amoebiasis and giardiasis. Control is achieved by treatment and improvement of sanitary conditions and water quality (Farthing *et al.* 2003).

1.2 Urbanisation in the regional context of sub-Saharan Africa

1.2.1 Urbanisation and health

In 2008, for the first time ever, more than 50% of the world's population will be living in urban settings. The highest rates of urbanisation currently occur in poor areas of Africa and Asia (United Nations 2006). Urbanisation profoundly impacts the life of a population, including health and well being, by transforming demographic, environmental and socio-economic characteristics.

The current urban transition occurs at an unprecedented rate and results in a highly and multi-layer heterogeneity. The pattern and extent of urbanisation depends on the global economy and there is an ongoing trend of convergence of urban and rural lifestyles (Cohen 2004). It is predicted that the majority of urban dwellers will not live in mega-cities, but in intermediate and smaller urban settlements (Cohen 2004). In secondary cities and towns, the coverage with basic services such as access to piped water, adequate waste(-water) disposal and electricity is largely insufficient (National Research Council 2003).

Because of a wide variety of the definition of "urban" between different sub-regions of the world, there exists no international standard. Most important definition criteria are based on population size and density, administrative boundaries, economic activities and service structures (Utzinger & Keiser 2006). The "urban environment" has been circumscribed as the physical environment of urban areas, including natural elements (i.e. air, water, land, climate, flora and fauna), and the built environment (the modified physical environment, i.e. constructions, infrastructures and open spaces) (Nunan & Satterthwaite 1999). The main factors driving urbanisation are (i) natural population increases (i.e. the excess of births over deaths), (ii) rural-urban migration, (iii) the coalescence of urban centres, and (iv) reclassification of settlements. A recent study on migration and urbanisation in francophone West Africa revealed, however, that rural-urban migration in sub-Saharan Africa is – albeit an important contribution factor to urbanisation – less dramatic than expected, and unemployment among migrants was lower than among non-migrants (Beauchemin & Bocquier 2004). Until the 1960s and 1970s, the colonial powers and existing commercial and administrative centres have strongly influenced the pattern of urban growth in Africa. After independence, many African cities continued to grow rapidly, often in the absence of a strong industrialization and foreign investment due to political instability, corruption and limited skilled labour (Cohen 2004).

Data suggest that, in general, the average health of people in resource-poor countries is better in urban areas than in rural areas. The causes are multifactorial including better physical access to, and coverage with health services and education (Godfrey & Julien 2005; Hay *et al.* 2005). However, poor urban people face similar health risks than the rural population (Keiser *et al.* 2004). Most important determinants of health among urban populations are their living conditions, the social and physical environment, access to health care, and social services that are governed by municipal, national and global trends (Galea *et al.* 2005; Vlahov *et al.* 2004). Urban slum dwellers have limited access to health and education because these areas are often not officially recognized by the public authorities (United Nations 2003). Improving health care and infrastructure, the key factor for the control and prevention of communicable diseases, is often impeded by chronic under-investment and a shortage of health workers, overpowering workload and brain drain (Godfrey & Julien 2005).

1.2.2 Ecologic transformations and parasitic diseases

Changes in land use and water-resource development, urbanisation, migration and lack of access to sound health services are major causes for the spread of human parasitic diseases such as malaria and schistosomiasis into new, formerly non-endemic zones. Over the past two decades, more attention has been given to the role of research to mitigate some of these negative effects (Conn *et al.* 2002; Knudsen & Sloof 1992; Mott *et al.* 1990; Mouchet & Carnevale 1997; Patz *et al.* 2000). Dense housing conditions, inadequate sanitation und lack of clean water, illegal waste dumps, and clogged surface-water drainage systems in urban zones create suitable habitats allowing the proliferation of a variety of disease vectors and intermediate hosts. Urban fringes and spatially heterogeneous occupied zones are particularly sensitive for the transmission of water-associated parasitic diseases. The simultaneous presence of “traditional” as well as “modern” health hazards is favoured by rapidly changing conditions in these zones of transition. Classical rural diseases are widely recognised now to create public health problems also in urban areas.

1.2.3 Urban malaria

Approximately 200 million people are living in urban malaria-endemic areas and annual clinical malaria episodes are estimated to range between 24.8 and 103.2 million in urban settings of sub-Saharan Africa, representing 6-28% of the global malaria incidence. Not only large urban cities but particularly small- and medium-sized towns are at risk of malaria (Keiser *et al.* 2004). The urban population is, on average, exposed to less intense malaria transmission and the frequency of clinical attacks is lower than in rural counterparts.

However, rapid and unregulated urbanisation increases the risk of malaria transmission due to poor housing and sanitation, improper drainage of surface water, open water bodies and augmented vector-breeding and human-vector contact (Martens & Hall 2000). Urban settings are fragile ecosystems where changes in weather patterns (e.g. El Niño Southern Oscillation) or socio-political unrests (e.g. civil war) may increase the risk of epidemics (Robert *et al.* 2003).

The epidemiology of urban malaria represents a challenge for the planning and management of public health needs, particularly the prevention and control of infectious diseases. Importantly, the urban context differs from the rural one and consequently, malaria control strategies successfully applied in rural areas need to be adapted before their transfer to urban settings (Donnelly *et al.* 2005). In the following section, some key features of the epidemiology of urban malaria are presented.

Lack or delayed immunity against malaria. In malaria-endemic urban zones, semi-immunity to disease is often acquired only in the late childhood or not at all due to the low level of transmission (Trape 1987). Hence, people at all ages might be at risk of malaria because they lack acquired immunity (Carme 1993; Gardiner *et al.* 1984; Keiser *et al.* 2004; Robert *et al.* 2003).

Small-scale heterogeneity. The prevalence and intensity of *Plasmodium* infections is often highly focal and heterogeneous within a small distance (Keiser *et al.* 2004; Njama *et al.* 2003; Robert *et al.* 2003; Trape 1987; Trape & Zoulani 1987a). The small-scale heterogeneity in urban malaria transmission patterns is a result of environmental modifications and urban development where land use and open water bodies (e.g. swamps, rivers and irrigated agricultural zones) change very dynamically (Utzinger & Keiser 2006). An urban endemicity gradient for malaria prevalence and of *Anopheles* breeding sites from the periphery areas towards the city centre has been observed in Ouagadougou (Sabatinelli *et al.* 1986; Wang *et al.* 2005) and Bobo Dioulasso, Burkina Faso (Guiguemdé *et al.* 1997), and in Yaoundé, Cameroon (Fondjo *et al.* 1992). Interestingly, a recent study of malaria prevalence between the city centre and the periphery carried out in Cotonou, Benin found a rather homogeneous distribution (Wang *et al.* 2006c).

Seasonality in semi-arid urban contexts. The impact of urbanisation is more pronounced in areas with low and seasonal mean annual rainfall (Robert *et al.* 2003). In these settings, the reproduction of malaria vectors in open water bodies and transmission are limited to the rainy season, as recently shown in Ouagadougou (Wang *et al.* 2005) and N'Djamena, Tchad (Othnigué *et al.* 2006).

Adaptation of vectors to urban settings. Lower vector density in urban areas are usually due to limited availability of clean freshwater sites and open spaces for breeding (Lindsay *et al.* 1990) and an increasing pollution of breeding sites (Trape & Zoulani 1987b). However, the breeding of malaria vectors in polluted water and urban ecosystems has been observed already two decades ago (Chinery 1984).

Rural-urban migration. The mobility of urban dwellers (intra-urban and urban-to-rural) is higher compared to people from rural areas. There is a risk of importing malaria from endemic rural zones; people act as active or passive transmitters when non-immune individuals travel to rural endemic areas and are infected there and in turn can transmit the parasite when they return to urban areas (Robert *et al.* 2003). Travelling away from major urban settings into rural areas as a risk factor for malaria has been reported in Burkina Faso (Sabatinelli *et al.* 1986), Zambia (Watts *et al.* 1990), The Gambia (Koram *et al.* 1995), Ghana (Klinkenberg *et al.* 2006), Tanzania (Wang *et al.* 2006a), and in Côte d'Ivoire (Wang *et al.* 2006b).

Socio-economic status and housing conditions. Poorer households generally have less resources to invest in health care and to improve housing quality (e.g. corrugated iron roofs, brick walls and screened eaves) which protects against mosquitoes entering the house (Lindsay *et al.* 2003). Poor housing conditions and crowding have been reported as risk factors for malaria (Koram *et al.* 1995) and houses with ceilings as protective factor in peri-urban areas of The Gambia (Lindsay *et al.* 1990). The use of ITNs for reducing the risk of malaria is well documented (Lengeler 2004). Important is also the neighbourhood of the house regarding sanitation and proximity to swamps and open water bodies. The exposure to open water bodies (e.g. fountains, swamps and rivers) as a risk factor in urban settings has been reported, for example, in studies conducted in Kampala, Uganda (Njama *et al.* 2003), and in Ouagadougou (Wang *et al.* 2005).

Land use and urban agriculture. Land use patterns affect the malaria transmission risk by creating *Anopheles* breeding sites. Close proximity of houses to swamps and streams has been found as a risk factor for malaria prevalence in Kampala (Staedke *et al.* 2003) and in Dakar, Senegal (Trape *et al.* 1992). To date, the effect of urban agriculture on malaria transmission has been investigated in a few studies only. Open-space irrigated vegetable production zones provide excellent conditions for productive *Anopheles* breeding sites in open water bodies, as it has been shown in market garden wells in Dakar (Robert *et al.* 1998), in small-scale farming zones ("Matuta") in Dar es Salaam, Tanzania (Castro *et al.* 2004; Sattler *et al.* 2005), and in urban areas of Kenya (Keating *et al.* 2003). However, another investigation comparing *Anopheles* breeding sites in agricultural with those in non-agricultural areas in two urban zones of Kenya found no significant differences (Keating *et al.* 2004). Living in proximity to areas of irrigated agriculture has been identified as a risk factor for malaria in Accra (Klinkenberg *et al.* 2005) and Kumasi, Ghana (Afrane *et al.* 2004), Yaoundé (Fondjo *et al.* 1992), Brazzaville, Congo (Trape & Zoulani 1987b) and in Ouagadougou (Wang *et al.* 2005).

There is less evidence regarding the effect of irrigated rice cultivation in urban neighbourhoods on the transmission of malaria. Many other factors interact, such as the type of the urban setting (e.g. large urban centre versus small town), the farming system (e.g. subsistence farming), the neighbourhood (e.g. poor settlements versus rich neighbourhoods), the socio-economic status, and household resources for health care and preventive measures (e.g. sleeping under an ITN). The effects of irrigated rice cultivation on malaria transmission are also not well documented because research has primarily focussed on mega-cities where commercial vegetable production is more widespread. Local irrigated rice production is, however, most often practiced in small- and medium-sized towns.

Several years ago, the "Systemwide Initiative on Malaria and Agriculture" (SIMA) has been launched. The purpose of SIMA is an enhanced understanding of the links between agriculture and malaria by promoting research and capacity building. The aim is to identify innovative adaptation strategies which reinforce existing malaria control in different agricultural systems (Donnelly *et al.* 2005). Emphasis is placed on research to mitigate negative effects of malaria on food security, nutrition and livelihood of urban farming households (Mutero *et al.* 2005; van der Hoek 2004). The initiators consider the urban environment as a sound entry point to reduce and control the burden of malaria. In a first step, geographic information system (GIS)-based approaches will be applied to assess the heterogeneity of urban malaria risk factors. In a next step, community-based interventions will be tested and implemented in different urban environments.

1.2.4 Urban schistosomiasis

Schistosomiasis, formerly described as a "classical rural" disease occurring in areas with poor sanitary conditions, has gained more focus in urban settings. Studies on urban schistosomiasis have been carried out in different parts of Africa and in Brazil. Most of these investigations were limited to descriptive characterizations of selected populations at high risk as for example studies done in Kampala (Kabatereine *et al.* 1996; Kabatereine *et al.* 1997), and in

Harare, Zimbabwe (Ndamba *et al.* 1994), and to the identification of transmission foci, such as in Addis Abeba, Ethiopia (Erko *et al.* 1996), Lusaka, Zambia (Mungomba & Michelson 1995), and Bamako, Mali (Dabo *et al.* 2003). Schistosomiasis is strongly associated with social, cultural, behavioural and economic factors and lifestyles that interact in a complex way with ecological and environmental factors at the local scale (Barreto 1991; Huang & Manderson 1992; Huang & Manderson 2005). The main interrelating factors are migration and urbanisation, socio-economic status, lifestyles, quality of sanitation and water supply, proximity to transmission sites, water contact behaviour and agricultural practices. Persistent cultural and social habits from rural areas carried into urban areas, i.e. domestic, agricultural and leisure activities, favour the transmission risk in urban zones. The risk of infection is related to the distance from infested water bodies e.g. rivers and creeks for activities such as washing clothes, bathing and fishing and subsequent water-contact patterns, as it has been shown in urban settings in Brazil (Firmo *et al.* 1996), and Cameroon (Njiokou *et al.* 2004). The poor maintenance of surface water installations in urban zones is partially responsible for the rapid expansion of urban schistosomiasis (Dabo *et al.* 2003). Rural-urban migration plays a key role and the life cycle is closed by the introduction of the parasite by migrants from endemic rural areas. In fact, migrants with a low socio-economic status are often forced to work in the informal sector, including urban farming. In large cities, urban agriculture expands in poor neighbourhoods and near informal settlements. The association between migration and urban schistosomiasis has been established in a town of Brazil (Ximenes *et al.* 2000).

Zones of irrigated agriculture in urban areas often offer favourable ecologic conditions for intermediate host snails through natural water bodies (e.g. rivers, creeks and ponds), as well as man-made water collections such as irrigation canals in rice paddies, wells, fish ponds for aquaculture and other open water bodies. Particularly in small- and medium-sized centres, persisting rural practices, such as irrigated rice cultivation in lowlands and swamps may contribute to the spread of schistosomiasis. Urinary schistosomiasis in a medium-sized town of Côte d'Ivoire was found to be related to irrigated rice cultivation rather than to vegetable growing (Fournet *et al.* 2004). Rapidly growing agglomerations in peripheral urban areas with poor sanitation and inadequately constructed habitations where peri-urban agriculture is widespread can result in high levels of schistosomiasis transmission. A spatial gradient of schistosomiasis endemicity from the periphery to the urban centre related to different levels of exposure to infested rivers and irrigation canals has been observed in Niamey, Niger (Ernould *et al.* 2000; Ernould *et al.* 2003).

1.2.5 Soil-transmitted helminthiasis and intestinal protozoan infections in urban settings

Informal settlements and slums associated with deteriorating environmental and socioeconomic factors may provide suitable conditions for the spread and persistence of hookworms, *A. lumbricoides*, *T. trichiura* and intestinal protozoa. Infective stages of embryonated *A. lumbricoides* and *T. trichiura* eggs are capable of enduring urban environmental extremes (Hotez *et al.* 2003). The intestinal protozoa *E. histolytica* and *G. duodenalis* often occur in urban slum environments, usually in unsafe drinking water supplies (Crompton & Savioli 1993). Soil-transmitted helminth infections were reported to be higher in urban than in similar rural settings of Malawi (Phiri *et al.* 2000) and Cambodia (Sinuon *et al.* 2003). However, higher frequencies were observed in villages compared to a province town in a recent study done in Cameroon (Ndenecho *et al.* 2002). Main risk factors for soil-transmitted helminths and intestinal protozoa in urban areas are inadequate sanitation, poor public hygiene, contaminated drinking water, contact with sewage and human excreta, low socio-economic status and related indicators (e.g. restricted access to health care, poor health education, poor household sanitation and personal hygiene, the level of maternal education, crowding, foot-ware and open defecation). Maternal education, for example, plays an important role in primary health care of children, food and water storage and handling of children's faeces (de Silva *et al.* 1996; Tshikuka *et al.* 1995). Family members may act as transmission sources, as it has been shown in an urban African setting where richer families accommodated children from families living in poor rural and slum areas – which is very common in Africa (Tshikuka *et al.* 1995). Improvements in public sanitation and waste management would reduce or eliminate these diseases, but the technical feasibility is limited in crowded urban environments, and implementation often moves ahead only at slow pace (Crompton & Savioli 1993).

Hookworm infections occur rather in rural than urban areas and are often linked to occupational exposure. Agricultural activities are an important contextual factor for hookworm infection, which is very common among farmers and vegetable growers (Brooker *et al.* 2004; Hotez *et al.* 2003). Peri-urban and urban zones with intensive agriculture are high-risk areas for hookworms in particular and soil-transmitted helminths more generally. Risk factors are the use of fertilizers based on human faeces and untreated wastewater, daily contact with agricultural soils, outdoor defecation, and a high population pressure combined with poor sanitation in temporary settlements of migrants (Cissé 1997; van der Hoek *et al.* 2003).

1.3 Urban agriculture in the regional context of sub-Saharan Africa

1.3.1. General issues

Ecologic and demographic transformations in the face of rapid urbanisation are key factors explaining intensive urban and peri-urban agricultural systems. Urbanised areas in Africa contain large amounts of arable open space that are suitable for food production (Nugent 2000). Urban agricultural activities in developing countries are part of the informal economy, but they play an important role in the food security, diet diversity and improving livelihoods (Moustier 1999). Urban agriculture often expands into undeveloped public and private land, and other areas unsuitable for construction. As the land tenure is often not clearly defined, open spaces are occupied occasionally. Numerous studies investigated whether and how the promotion of urban agriculture contributes to urban food security, employment and livelihood strategies for urban poor, and the valorisation of urban waste. It is encouraging to note that empirical research on urban agriculture has been strengthened also in terms of water shortages, health concerns, conflict over land tenure and cultivation practices (Ellis & Sumberg 1998).

1.3.2 Historical aspects of urban agriculture

Urban agriculture has been established already in pre-colonial African cities, and the practice of traditional market gardening has a long tradition (Winters 1983). During the colonial period, urban vegetable gardening experienced new dimensions through technical improvements in many sub-Saharan towns, for example in Accra (Asomani-Boateng 2002), Bamako (Zallé 1999), Dakar (Mbaye 1999), and in Dar es Salaam (Howorth *et al.* 2001). Vegetables were produced to satisfy the alimentary preferences of the expatriate colonial administration and traders (Zallé 1999). In Harare, market gardens were built to plan ahead against probable food shortages during the First World War (Hubbard & Onumah 2001).

After independence in the 1970s and 1980s, declining economies resulting in currency devaluation, external debts, and excessively increasing food prices, and policy reforms under structural adjustment programmes (SAPs) cut employment, particularly in the public sector (Maxwell 1999). The economic crisis and drought periods with subsequent food shortages in the 1990s further amplified rural-to-urban migration. Urban agriculture expanded within these periods and developed into a survival strategy of the urban poor to sustain their livelihoods (Bryld 2003; Page 2002). Within the period of economic crisis, a few African governments tolerated farming in cities. In Ghana, Nigeria and Tanzania, for example, urban municipalities even encouraged urban residents to grown their own food (Asomani-Boateng

2002; Jacobi *et al.* 2000; Lynch *et al.* 2001). The increased demand for fresh products associated with changing lifestyles and alimentary habits in cities also led to the evolution of urban agriculture (Zallé 1999).

1.3.3 Urban agriculture and policies

Nowadays, ambiguity prevails in many African cities on the issue of urban agricultural land use, owing to an inconsistent handling of the tenure system and legal rights by the responsible authorities. Urban agriculture was viewed for a long time as a "ruralisation" of the city by imported rural lifestyles, and was therefore seen as an inappropriate activity in the urban area which retards the economic development (Bryld 2003; Page 2002). The city and the countryside were considered as separate entities where industrial activities were related to "urban" and agricultural activities to "rural". This conceptual framework led to a marginalisation of urban agriculture and a displacement into informality in city planning policies (Cissé *et al.* 2005). Urban agriculture blocks terrain that could be used for higher-value land use and is often linked to informal settlements. These areas were sometimes razed in order to control squatter settlements, as for example in Harare (Hubbard & Onumah 2001). These developments and resulting health risks have reinforced governments and municipal authorities to marginalize urban agriculture (Baumgartner & Belevi 2001; Drechsel *et al.* 1999; Lock & de Zeeuw 2002). The lack of the institutional regulation of urban agricultural development in cities provokes conflicts and social tensions between different stakeholders on land and water access.

Since the 1990s, there have been several promising initiatives to advance urban agriculture, e.g. through credit and technical assistance for urban farmers in Nigeria (Mougeot 1998), Senegal (Mbaye 1999), and in the Congo where the development and maintenance of urban agriculture is promoted by interconnected associations of producers and market traders (Moustier 1999). In Uganda and Zambia, steps towards a legalization of urban agriculture have been undertaken (Bryld 2003), and in Niger, urban agricultural land use has been integrated into the city planning, including the intensification of market gardening along the Niger River in Niamey (Cissé *et al.* 2005). More recently, a network of urban agriculture was created in seven West African countries that aim at enhancing research and consultation activities in view of a sustainable development of urban agriculture in West Africa (Cissé *et al.* 2005).

1.3.4 Definition and characteristics of urban agriculture

There is a variety of definitions in the growing literature about food production in urban and peri-urban areas (Mougeot 1999; Smit *et al.* 1996). We use the following definition: "*Urban agriculture comprises the production, processing and distribution of a diversity of foods, including vegetables and animal products within intra-urban or at peri-urban areas. Its main motivation is food production for personal consumption or sale and/or higher income*" (Baumgartner & Belevi 2001). High-value and highly perishable products, consumed mainly by farmers themselves and by local populations are produced within a limited space (Nugent 1999). In his "model of agricultural land", Thünen (1826) highlighted the importance of transportation costs; the agricultural land use pattern is determined through distance which influences transportation and handling costs for food. High-yield and perishable crops are grown closest to the centre as a result of high competition over land and water, extensive field crops (e.g. cereals and potatoes) that can be stored and livestock are produced in zones most distant from the city (Bogetic & Sanogo 2005; Drechsel *et al.* 1999).

In the mid-1990s, urban agriculture, including crops, livestock and fish, was practiced by an estimated 800 million people, particularly in Asia (Smit *et al.* 1996). In Africa, there is a wide spectrum of production systems, ranging from household subsistence farming to large-scale commercial production. Urban agriculture is part of the informal economic sector and represents one way of insertion into the urban economy for rural-urban migrants. The practice requires no or very limited training and relies on indigenous resources and skills, technologies are labour intensive and adaptive, and urban agriculture operates at a small-scale (Howorth *et al.* 2001; Lee-Smith & Memon 1994). Drechsel and colleagues stratify urban vegetable farmers into three main groups, according to the production types, namely (i) "urban shifting cultivator", belonging to the poorest and most vulnerable group with no or very limited rights to use the land and therefore moving from empty space to empty space; (ii) "household gardeners" who are residents of the town with more secure land rights, cultivating subsistence and cash crops; and (iii) "peri-urban market producers", often specialized farmers with formal land rights and market access producing high-value vegetables (Drechsel *et al.* 1999).

1.3.5 Potentials of urban agriculture

Urban agriculture holds considerable untapped economic potential (Drechsel *et al.* 1999), and hence it can play an important role in achieving the Millennium Development Goals (MDGs), in particular MDG 1, which aims to "eradicate extreme poverty and hunger" by supplying food and creating employment for urban poor, and MDG 7, which aims to "ensure environmental sustainability" by improving the physical environment of urban areas. The most important potentials of urban agriculture are summarized below.

Food supply and employment. Urban agriculture provides fresh and high-quality food for urban dwellers and is a source of economic growth through local food provision. It can alleviate poverty and mitigate vulnerability of poor urban households by the creation of employment and livelihood opportunities. Fluctuating salaries of the poor can be complemented with subsistence production (Hubbard & Onumah 2001; Nugent 1999; Smit *et al.* 1996). Household expenditure for food purchases is reduced and these resources can be used for other needs, e.g. for school fees or health care (Bryld 2003; Page 2002). Jobs associated with urban agriculture are generated, for example thorugh the production and provision of agricultural inputs (e.g. fertilizers), and the commercialisation of agricultural products. Often, whole households are engaged in food production and commercialisation; one part is predominantly active in the labour-intensive production and the other part is responsible for the selling of the products on local markets (Armar-Klemesu & Maxwell 2000; Asomani-Boateng 2002; Dongmo *et al.* 2005). In general, it has been recognized that the informal sector has economic advantages by absorbing surplus labour and by building a safety-net in an environment characterized by high unemployment rates and poverty (Becker *et al.* 1994). In most West African cities, cash-crop farming activities in large urban cities are dominated by men, whereas traditional vegetable farming in rural areas and small urban centres are carried out by women (Kessler 2004). Urban agriculture thus has potential to encourage employment of women and the establishment ofwoman's associations ("cooperatives des femmes") in African cities (Drechsel *et al.* 1999; Freeman 1993; Wilbers & Hovorka 2004).

Productive space management. Unused, unexploited and degraded land is valorised, improving the aesthetic value of landscapes in cities. Cultivated areas enhance the security of neighbourhoods because bush land and other possible hiding places for thieves are cleared (Bryld 2003; Lynch *et al.* 2001). Cultivated zones also protect against squatter, garbage deposits and dumping (Mougeot 1994).

Environmental management and sustainable land use. Urban organic waste, such as compost, household refuse, night soil and wastewater can be re-used in a productive way if recycled properly. Agro-industrial by-products (e.g. poultry manure) can be valorised as alternative fertilizer. Composting can counteract against land impoverishment and may reduce human-induced erosion through cultivation. Trees and plants reduce air pollution by photosynthetic activity, increase humidity and preserve groundwater. Cultivated areas protect against inundation by water and they create ecological niches and habitats through green belts (Smit *et al.* 1996).

1.3.6 Health risks related to urban agriculture

Although urban agriculture unarguably has positive effects on public health, it also comes at a price, e.g. from the use of contaminated wastewater and the creation of potential mosquito breeding sites in zones of irrigated agriculture, which might lead to enhanced transmission of soil-transmitted and vector-borne diseases. Higher incidences of water-associated diseases lead to increased health costs and losses of economic productivity. A study from Gockowski and colleagues showed that urban farmers working in lowlands of the suburbs of Yaoundé spent two times more on their health than producers that were not working in lowlands (Gockowski *et al.* 2003). Health risks associated with urban agriculture occur through contamination, e.g. by the use of improperly treated wastewater, compost, and manure, and by occupational exposure, which means water-contact behaviour and frequency and proximity to potential transmission sites. Crops can be contaminated with heavy metals, e.g. on road sides, or from agricultural inputs, as it has been shown in urban market gardens using town refuse (Pasquini 2006), or municipal waste in Nigeria (Anikwe & Nwobodo 2002). Industrial and municipal sources of used water can contain high levels of toxins, as shown by a study from Kano, Nigeria (Binns *et al.* 2003). Despite the advantages of composting, heavy metals can be introduced into the food cycle if improperly managed (Birley & Lock 1998).

1.3.7 Challenges experienced by urban food producers

Among the most important problems of the urban cultivators is their limited and insecure access to land, forcing them to the unauthorized use of open spaces on roadsides, as well as public and private sites under construction. The poorest are not always the major beneficiaries of land; access is often a source of corruption and conflicts between the producers themselves. Producers with sufficient financial resources may hoard land and impound high taxes from their successors, as observed in Bamako (Zallé 1999). Since the cultivation in urban areas is often not recognized as a legal activity, farmers are obliged to generate the maximum output within a short period. Soils are at risk to erode, dry up and salinise due to the intensive application of fertilizers and other chemical products (Bowyer-Bower & Smith 1999; Bryld 2003). Urban farmers are often not acquainted with dosage of agro-chemical plant treatments, how frequently the product can be used and when it should be employed last before harvest. Thus, this lack of knowledge and exposure to chemicals bears public health risks for producers and consumers alike (Faria *et al.* 2005). Since urban farming is not taken into account as legal land use in most of the African cities, no service by agricultural institutions is provided for urban farmers (Bryld 2003; Dongmo *et al.* 2005). Difficulties in the marketing and commercialisation of urban agricultural products can be explained partially by poor organization within the commercial system, price fluctuations, local taxes, and by competition from imported products (Asomani-Boateng 2002; Cissé *et al.* 2005). It is noteworthy that often the producers among themselves are not or only very poorly organised (Cissé *et al.* 2005).

1.3.8 Recommendations and policy implications

There is a broad consensus in the current research on urban agriculture about its recognition as a valuable urban land use, competing with industry, housing and commerce. The promoters of urban agriculture require the institutionalisation and the formulation of national policies in a framework of partnership, involving all stakeholders (national structures, municipal authorities, producers and others) in these processes (Bryld 2003; Drechsel *et al.* 1999). City planners and local governments could regulate access to land and water in a rational management of urban space. Vacant land in urban and in peri-urban areas of lower population densities could be secured for cultivation (Mougeot 1999). Zones of periodical flooding that are often inhabited by the urban poor in squatter settlements could be reserved for agricultural land use in order to improve space productivity and protect neighbouring built-up areas through “flood buffers” (Howorth *et al.* 2001; Lynch *et al.* 2001). GIS and remote sensing technologies that allow a detailed mapping of zones of different urban land use are helpful tools in the spatial and temporal monitoring of urban agricultural zones, the coordination of urban planning and the allocation of vacant land in cities (Fazal 2000; Luck & Jianguo 2002).

1.4 The local context of Côte d’Ivoire

1.4.1 Agriculture and national economy

Agriculture has been and continues to be the backbone of the Ivorian economy. Among the total labour force in 2004, 45% were engaged in the agricultural sector. Agricultural exports constituted 58% of the total export (FAO 2005). For example, Côte d’Ivoire remains the largest cocoa producer and exporter in the world (FAO 2005). Coffee, cotton and, to a lesser extent, rubber and timber also rank among the main export products. Following the “dual economy" model adopted after political independence in 1960, the agricultural sector was considered as the basis for industrialization and economic development, and hence the government made this sector the main focus of its policy (Blunch & Verner 1999; Bogetic & Sanogo 2005). The rapid economic growth of Côte d'Ivoire in the 1970s and 1980s was based on a successful agro-industrial economic period; revenues were acquired from agro-exports to develop the agro-industrial sector and stimulate import-substituting enterprises (Liadé 1998; Soulé 2003). Over the past two decades, agricultural diversification gained in importance, but still the export market is dominated by a small number of products. Key determinants for the declining Ivorian economy during the late 1980s and 1990s were structural problems based on regional economic and social disparities, the national economy's dependency on the international market and its sensitivity to fluctuations in international crop prices (e.g. due to price dumping from the Asian region) (Bogetic & Sanogo 2005; Soulé 2003; World Bank 2002a). This period induced, at household level, a shifting back to agricultural activities, with a reduction of the household income share from non-farming activities (Barrett *et al.* 2001). The political instability by the end of the 1990s culminated in a socio-politic crisis (coup d'état in 1999) and a civil war commencing in September 2002 and ending formally in July 2003 (Akindès 2004; Woods 2003). Regional development themes are since ruled out from the political agenda that is dominated by post-conflict-related issues.

The natural resources base of Côte d'Ivoire is rich and ranges from the humid South to the sub-humid climatic zone (North). Two main agro-ecologic regions with different farming systems can be distinguished, namely (i) the forest with annual precipitation of 1,200-1,800 mm, and (ii) the savannah region with annual precipitation of 900-1,200 mm. In rural areas, traditional low-technology and land-extensive subsistence farming systems prevail. The region's economy of the forest zone is predominantly based on coffee and cocoa production. In addition, there is production of palm oil, rubber, coconut, pineapple and banana. The major food crops for sale and subsistence are, in order of importance, maize, rice, plantain, yams, and cassava (area harvested, FAO 2005). Rain-fed food crops, mainly maize, rice, yams and groundnuts, dominate the savannah zone. Main cash crops in the savannah region are cotton and tree crops (cashew, mango and karité). An additional important local income base is livestock (World Bank 1997). The agricultural land use has been considerably modified by intensive crop systems and industrial plantations in agglomeration zones of big urban centres (Ademola-Ouattara *et al.* 1999).

1.4.2 Urbanisation

Over the past three decades, Côte d'Ivoire has experienced a profound social and demographic transformation. The primarily rural society altered into an increasingly urban society. In 1948, there were only two cities counting more than 10,000 inhabitants and 13 towns with more than 4,000 inhabitants. At political independence, the population of Côte d'Ivoire was estimated at 3.7 million. The urban population accounted for only 19%. There were 11 cities with more than 10,000 inhabitants and 26 towns with more than 4,000 inhabitants (Kull 1998). In 2000, the estimated population was 15 million with an annual population growth of 2.6%, whereof 46% were living in urban areas and one of five in the economic capital Abidjan (World Bank 2002b). Other important urban centres comprise Bouaké, Yamoussoukro, Daloa and Gagnoa in the centre, Korhogo in the north and Man in the west (Figure 1.6). In these towns, industrial production and processing of agricultural products is concentrated and the towns serve as market nodes. The informal sector remains the major economic engine and the large majority of young people (aged between 15 and 34 years) are involved (Touré 1995). In Abidjan, multi-function areas evolved from different economic activities around large urban markets, as for example in the districts of Adjamé and Treicheville which play an important role in the organization of the urban space (Freund 2001; Kouassi 1999).

1.4.3 Urban agriculture in Côte d'Ivoire

Vegetable production for urban markets in Côte d'Ivoire progressed with the extension of cities, particularly around zones of the large urban centres of Abidjan, Bouaké, and Yamoussoukro. The typical profile of vegetable producers in Abidjan is that they are male immigrants with vegetable cultivating as their principal activity. In general, these urban farmers have a very low seed capital and no professional agricultural training, hence they are trained by experienced fellows. The main agricultural products are off-seasonal crops, such as short cycle vegetables (e.g. leaf crops) farmed in intra-urban zones of high economic pressure, and long cycle vegetables (e.g. fruits and tubers) in peri-urban areas (AGRISUD 1999; Tano *et al.* 2002).

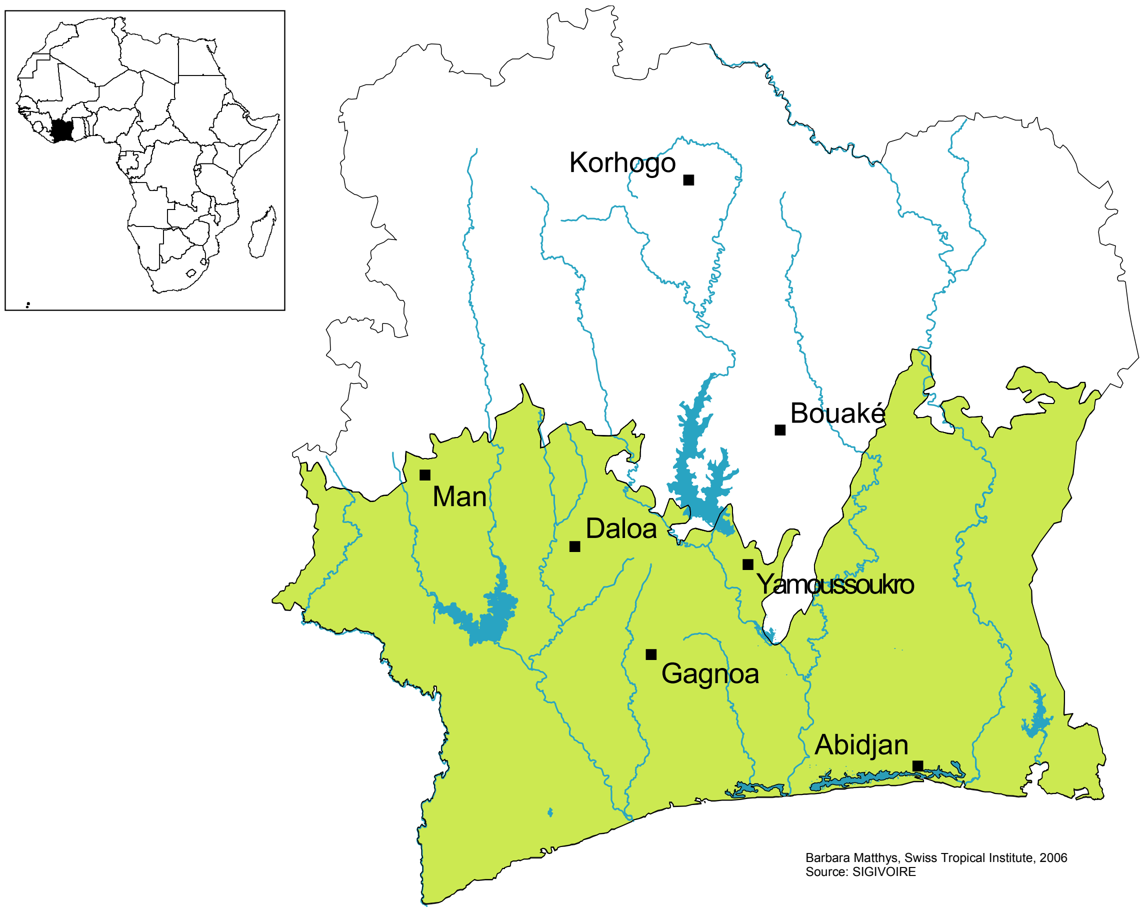


Figure 1.6 Major urban centres in Côte d'Ivoire

In the politic capital Yamoussoukro, market gardening is recognized by the municipal authorities as official land use. In contrast, in Abidjan and most other towns of Côte d'Ivoire, urban vegetable production for local markets evolved under illegal conditions and still remains an unauthorized activity (AGRISUD 1999; BNETD 2001). Production sites expanded on precarious lands, most often on lagoon shores, along roadsides, on un-constructed land of private and public societies, military land, and privately-owned house parcels. A recent land use classification revealed that 67% of the vacant areas within the city administrative boundaries of Abidjan were cultivated zones, but many sites are shrinking or have already been absorbed by construction (BNETD 2001). According to a government decree of 1967, land belongs to the person who brings it into production provided that formal registration is done (Heath 1993). This means that the state owns vacant land, which can be sold to private parties, but it has to be registered in the land book. In rural areas, the village council plays an important role in land allocation for cultivation. However, decisions are more and more decentralized and a process of privatisation is taking place (Colin & Ayouz

2006; Lopez 1998). Since legal land and housing are only affordable to populations with higher income in urban areas, the poor often acquire land directly from customary chiefs, by-passing the legal processing of land acquirement. Few interventions which aimed at upgrading of informal settlements in Abidjan and other cities of Côte d'Ivoire have been implemented, but without involving the issue of urban agriculture (Obrist *et al.* 2006; World Bank 2002b).

A project on the advancement of urban and peri-urban agriculture in Abidjan has been proposed by national planning structures (Bureau National d'Etudes Techniques et de Développement, BNETD) within the framework of a "Network for Urban Agriculture in West and Central Africa" (RFAU/AOC) and in collaboration with international partner organizations. The objective is to investigate the capacities and instruments for arable land conservation (BNETD 2002a). In a first step, access constraints to land for cultivation in Abidjan have been examined. Secondly, a city planning scheme of Abidjan ("schéma directeur de la ville d'Abidjan") defining the actual urban infrastructure, land use and land availability has been established. This planning scheme shows potential reserve areas in peri-urban zones of Abidjan and represents a proposal for future planning (BNETD 2002b).

1.4.4 Production systems in peri-urban areas and small urban centres

Urban agriculture in small and medium-sized towns is strongly influenced by subsistence-based familial production. Traditional rice cultivation and market gardening form the principal supply for urban markets. Local varieties of rice and vegetables are produced, such as local aubergines, okra, pepper, and leaf vegetables. The vegetable production is often seasonal during the rainy season and rain-fed crops (e.g. aubergines and tomatoes) are grown on plateaus.

Peri-urban production in catchment areas of large cities is characterized by year-round production for urban market supply, informal land use and production on small plots (Tano *et al.* 2002). The agricultural land use in these areas is concentrated in lowlands, riverbanks and watersides of lakes, and in zones of sandy soils.

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2. Goal, objectives and study area

2.1 Goal

The overarching goal of this thesis was to enhance our understanding of agricultural land use and typical agricultural activities and their effects on the frequency and distribution of major human parasitic diseases in different urban settings of Côte d'Ivoire. Particular emphasis was placed on malaria, schistosomiasis, soil-transmitted helminthiasis (ascariasis, hookworm disease and trichuriasis) and intestinal protozoan infections.

2.2 Main objective

The main objective was to determine contextual determinants and risk factors for major parasitic infections among urban farmers and their families by qualitative and quantitative methods.

2.3 Specific objectives

- To determine the socio-demographic profile of farming communities in two different urban settings of Côte d'Ivoire, and to assess the predominant farming systems, including main crop types, land tenure, and farming practices.
- To assess the socio-economic status, water contact patterns and water use, and perceived health problems of urban farmers and to compare them with non-farming households.
- To assess and compare the prevalence and intensity of human parasitic infections (*Plasmodium* spp*., S. mansoni*, soil-transmitted helminths and intestinal protozoa) in farming and non-farming households and to identify risk factors for infection.
- To identify productive *Anopheles* breeding sites in selected zones of agricultural land use in the rainy and in the dry season.
- To propose environmental control measures taking into account local eco-epidemiological features.

2.4 Study area

The two main study areas where the current investigations were carried out were (i) the economic capital Abidjan in the south-eastern part of Côte d'Ivoire (geographic coordinates: 5° 20' N // 4° 02' W; 3.3 million inhabitants), and (ii) Man, a medium-sized town and district centre in the western part of Côte d'Ivoire (7° 24' N // 7° 33' W; 115,000 inhabitants). In addition, in September 2002, we conducted a questionnaire survey on farming practices and land use patterns with 75 randomly selected households in the village of Zouatta II, located 25 km east of Man. This study was embedded in a cross-sectional community-based survey as part of a previous PhD thesis by Giovanna Raso, which was completed in December 2004 (Raso 2004).

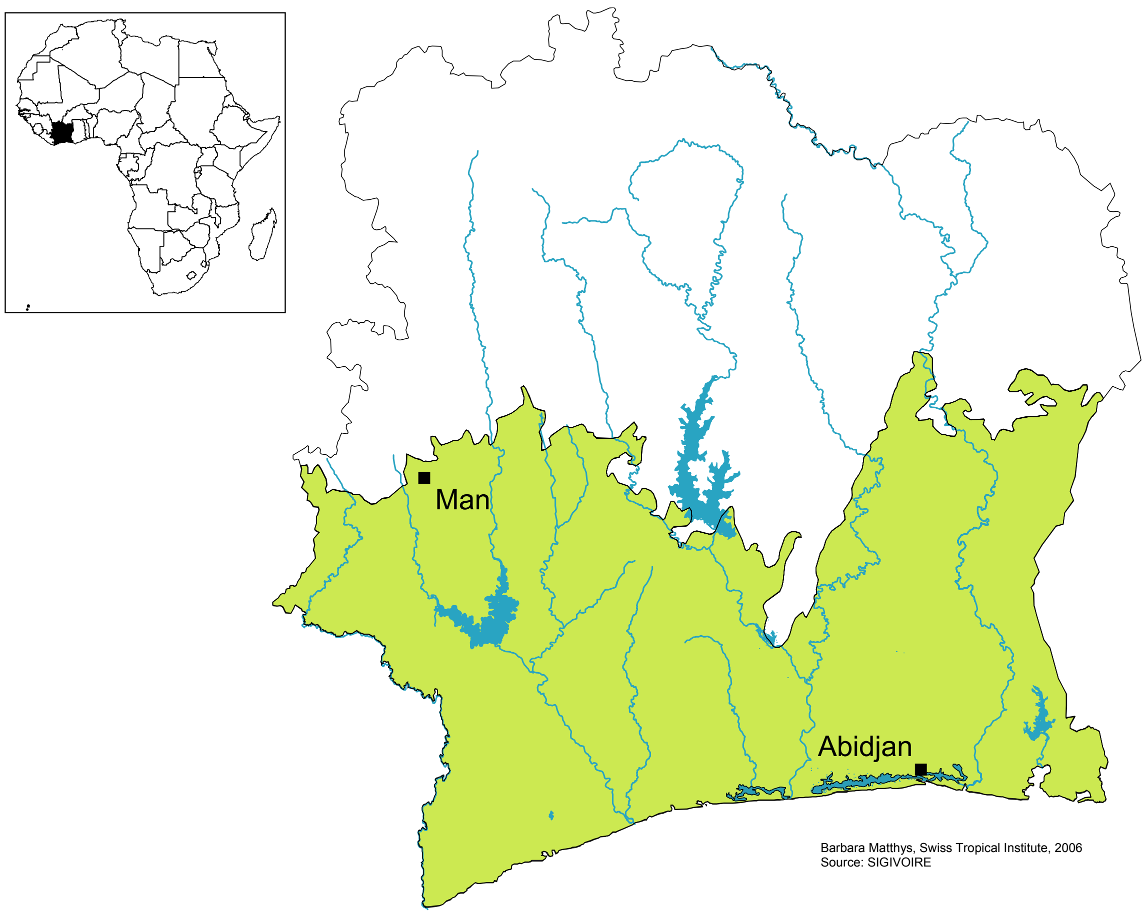

Figure 2.1 Map of Côte d'Ivoire illustrating the tropical rainforest area (green) and the savannah area (white), and the two study zones of Abidjan and Man.

2.5 Reference

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3. Maraîchers à Abidjan, Côte d'Ivoire: préoccupations sanitaires et maladies parasitaires

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Working paper

3.1 Résumé

L'agriculture urbaine, pratiquée dans les pays en voie de développement, possède de nombreux potentiels, tels que la satisfaction des besoins de produits frais et une subsistance améliorée pour des populations vulnérables. Mais elle peut impliquer des risques sanitaires qui passent par l'occupation du terrain et par l'activité agricole, qui peuvent rendre vulnérable à la transmission des parasites liés à l'eau et à des vecteurs de maladies. Le profil démographique et socio-économique de 189 cultivateurs de 7 zones maraîchères à Abidjan, Côte d'Ivoire, a été évalué et les préoccupations professionnelles et sanitaires comparés avec les prévalences de *Plasmodium* et des vers intestinaux. En dehors des recommandations portant sur le cadre administratif de l'agriculture urbaine, nos résultats donnent une base pour l'élaboration future des stratégies de contrôle et de protection adaptées pour ces zones à risques élevés de maladies.

3.2 Contexte

L'accroissement de la population urbaine en Afrique est accompagné par une augmentation des besoins en produits agricoles, ce qui a incité la progression des systèmes d'agriculture intensifs urbains et périurbains. Dans la ville d'Abidjan, capitale économique de la Côte d'Ivoire qui comptait presque 3 millions d'habitants en 1998, les zones de production maraîchères se créent spontanément, souvent dans les berges lagunaires comme à la Corniche de Cocody et sur des terrains des sociétés privées ou de l'état, par exemple à Marcory « Anoumambo » (Agence de Télécoms de Côte d'Ivoire, ATCI).

La création, le développement et la disparition des zones maraîchères urbaines sont très soudains. D'après une étude menée par le BNETD (BNETD 2002), une des raisons explicatives pourrait être l'accès aux terrains qui constitue un des problèmes majeurs des cultivateurs pour l'extension de leurs surfaces cultivées. Cet accès dépend entre autre de la reconnaissance des besoins de terrains cultivables par le Ministère de l'Urbanisme, des propriétaires terriens villageois et des capacités financières des petits producteurs. Les cultures maraîchères fréquemment observées dans la ville sont des légumes à feuilles (p. ex. salade, menthe, épinard et choux), des légumes fruits (p. ex. poivron et aubergine locale) et des légumes bulbes (p. ex. oignon et poireau). Le maraîchage à Abidjan est pratiqué par des citadins d'une population souvent marginalisée et les producteurs bénéficient très rarement de l'appui des structures agricoles spécialisées telles que de l'Agence Nationale d'Appui au Développement Rural (ANADER). La première démarche est de créer une base de discussion en vue d'établir ultérieurement des liens entre l'agriculture et les risques sanitaires, qui pourraient contribuer à comprendre mieux la vulnérabilité des producteurs maraîchers urbains.

L'objectif de la présente étude est de caractériser le profil démographique, socio-économique et sanitaire des cultivateurs de zones maraîchères à Abidjan. En particulier, il s'agit de mettre en relation les préoccupations sanitaires avec d'autres difficultés prononcées sur les sites de production, et de comparer la fréquence des maladies perçues par les ménages avec leur prévalence réelle.

3.3 Zone d'étude et méthodologie

Figure 3.1 démontre la zone d'étude. Elle comprend 7 zones de production maraîchères, qui se trouvent dans différentes communes urbaines d'Abidjan : Koumassi Camp Commando (zone 1) ; Koumassi Aklomiambla (zone 2) ; Marcory Sans Fil (zone 3); Marcory ATCI I & II (zone 4 et 5), Port-Bouët Agence pour la Sécurité de la Navigation Aérienne en Afrique (ASECNA), zone 6 ; et Cocody M'Pouto (zone 7). Les coordonnées géographiques d'une parcelle sur laquelle les cultivateurs travaillaient pendant les enquêtes étaient enregistrées à l'aide d'un système de positionnement globale (GPS).

Dans les 7 zones de production, nous avons effectué des interrogations avec 189 producteurs maraîchers qui ont été identifiés sur les sites de production en septembre / octobre 2004 et en mars 2005, et leur consentement obtenu pour la participation de l'étude. Le questionnaire portait sur les variables démographiques et socio-économiques, les activités agricoles, les sources et l'utilisation de l'eau et la perception des maladies.

Les membres de 133 ménages cultivateurs ré-identifiés en avril 2005 étaient invités à participer à un examen parasitologique, organisé dans les différentes zones maraîchères en mai 2005. Chaque personne fournissait un échantillon de selles le matin du jour de l'enquête et une goutte de sang sur place. Les échantillons de selles étaient divisés en deux pour obtenir deux répétitions, et étaient ensuite préparés le jour même selon la méthode de Kato-Katz (Katz *et al.* 1972). Une quantité de 1 à 2 grammes de selles de chaque échantillon était conservé dans un tube contenant 10 ml de sodium acetate-acetic formalin (SAF) et la présence des nématodes susmentionnés et des cystes ou trophocoïtes des protozoaires intestinaux, par exemple *Entamoeba histolytica*/*E. dispar* et *Giardia duodenalis* étaient notés.

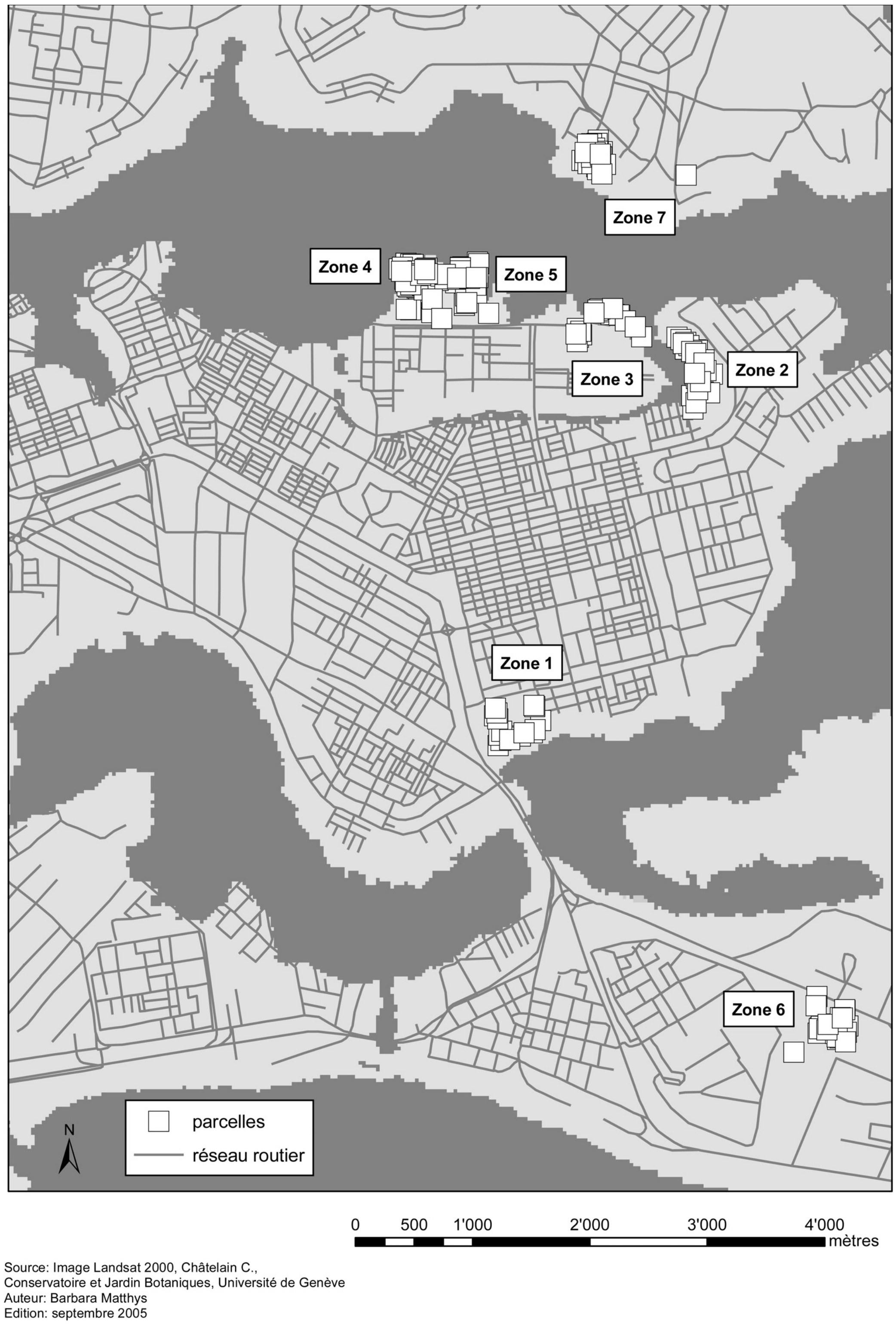

Figure 3.1 Zones maraîchères étudiées à Abidjan

Les lames étaient lues sous un microscope par des techniciens des laboratoires de l'Université de Cocody et du CSRS. La présence et la charge des nématodes (ancylostomes*, Ascaris lumbricoides, Trichuris trichuria*), et du trématode *Schistosoma mansoni* ont été notées. Suivant la méthode du test de goutte épaisse et frottis sanguin, les lames de sang ont été fixées avec la solution de Giemsa et les présences de *Plasmodium falciparum* et *P. malariae* relevées. La lecture de 10% des échantillons sélectionnées aléatoirement pour le contrôle de qualité a été effectuée pour les deux types d'analyse parasitologique.

Une dose unique de 400 mg d'albendazole a été administrée par un médecin à tous les participants sauf les femmes enceintes et les bébés moins de 12 mois. Les cas positifs à *S. mansoni* ont été traités avec une dose unique de 40 mg/kg de praziquantel. Ces deux traitements se réfèrent aux standards de l'Organisation Mondiale de Santé (WHO 2002). On a prescrit un traitement anti-paludéen (amodiaquine) aux personnes chez lesquelles des symptômes paludéens étaient diagnostiqués par le médecin, conseillé par le programme nationale de lutte contre le paludisme de Côte d'Ivoire.

3.4 Résultats et Discussion

Le profil démographique et socio-économique des cultivateurs varie peu entre les 7 zones d'étude (Tableau 3-1). La nationalité est en général non-ivoirienne. Pratiquement tous les cultivateurs sont d'origine du Burkina Faso, pays limitrophe au Nord, et en majorité des musulmans (88,8%). Tous les cultivateurs interrogés sont de sexe masculin, dont 82,0% mariés, à l'exception de la zone 2 où nous avons rencontré de nombreux producteurs célibataires (35,7%). Cette zone était la plus affectée par la disparition des parcelles cultivables, suite à une dynamique en faveur de la construction immobilière privée. La majorité des producteurs (58,9%) sont en charge des ménages avec 4 personnes ou plus. Le taux d'alphabétisation est faible (20,2%) et plus de la moitié des cultivateurs interrogés (52,7%) n'avaient jamais fréquenté l'école. Seulement 4 sur 188 personnes (2,1%) ont rapporté avoir suivi une école secondaire. Presque tous les producteurs (97,8%) pratiquaient leurs activités sans avoir reçu une formation professionnelle. L'agriculture constitue pour 68.8% l'unique activité, pendant que 31,2% ont une deuxième occupation comme le gardiennage ou l'artisanat (maçonnerie et mécanique).

Tableau 3-1 Profil démographique et socio-économique des cultivateurs

		Zone 1		Zone 2		Zone 3		Zone 4		Zone 5		Zone 6		Zone 7		Total	
		n	**n (%)**	**n**	**n (%)**	**n**	**n (%)**	**n**	**n (%)**	**n**	**n (%)**	**n**	**n (%)**	**n**	**n (%)**	**n**	**n (%)**
Nationalité	Burkinabé	20	19 (95,0)	28	27 (96,4)	22	22 (100)	32	32 (100)	35	35 (100)	27	26 (96,3)	25	21 (84,0)	189	182 (96,3)
	Malien		0		0		0		0		0		0		3 (12,0)		3 (1,6)
	Ivoirien		1 (5,0)		0		0		0		0		0		1 (4,0)		2 (1,1)
	Autre nationalité		0		1 (3,6)		0		0		0		1 (3,7)		0		2 (1,1)
Situation matrimon.	Marié	20	19 (95,0)	28	18 (64,3)	22	18 (81,8)	32	29 (80,2)	35	28 (80,0)	27	24 (74,1)	25	23 (93,0)	189	155 (82,0)
	Célibataire		1 (5,0)		10 (35,7)		4 (18,2)		3 (9,4)		7 (20,0)		7 (26,0)		2 (8,0)		34 (18,0)
Nmbre pers. par ménage	Moyenne[a]	19	3,8	27	1,9	22	4,0	31	4,1	34	3,7	27	3,6	25	5,5	185	3,6
	Range		(1-15)		(1-12)		(1-10)		(1-25)		(1-14)		(1-18)		(1-15)		(1-25)
Religion	Musulman	20	18 (90,0)	28	24 (85,7)	22	21 (95,5)	32	29 (90,6)	35	33 (94,3)	26	25 (96,2)	25	17 (68,0)	188	167 (88,8)
	Chrétien		2 (10,0)		4 (14,3)		1 (4,6)		3 (9,4)		2 (5,7)		1 (3,8)		8 (32,0)		21 (11,2)
Niveau d'études	Pas allé à l'école	20	14 (70,0)	27	12 (44,4)	22	9 (40,9)	32	18 (56,3)	35	18 (51,4)	27	13 (48,2)	25	15 (60,0)	188	99 (52,7)
	Ecole coranique		5 (25,0)		8 (29,6)		6 (27,3)		8 (25,0)		11 (31,4)		5 (8,5)		8 (32,0)		51 (27,1)
	Ecole primaire		1 (5,0)		6 (22,2)		6 (27,3)		6 (18,8)		6 (17,1)		7 (25,9)		2 (8,0)		34 (18,1)
	Ecole secondaire		0		1 (3,7)		1 (4,6)		0		0		2 (7,4)		0		4 (2,1)
Formation agricole	Sans formation	20	20 (100)	26	26 (100)	22	20 (90,9)	31	31 (100)	35	34 (97,1)	26	25 (96,2)	24	24 (100)	184	180 (97,8)
	Formation		0		0		2 (9,1)		0		1 (20,9)		1 (3,9)		0		4 (2,2)
Occupation principale	Agriculture	20	17 (85,0)	28	21 (75,0)	22	15 (68,2)	32	28 (87,5)	35	31 (88,6)	27	26 (96,3)	25	23 (92,0)	189	161 (85,2)
	Gardiennage		2 (10,0)		5 (17,9)		7 (31,8)		3 (9,4)		1 (2,9)		1 (3,7)		1 (4,0)		20 (10,6)
	Artisanat		1 (5,0)		1 (3,6)		0		0		1 (2,9)		0		1 (4,0)		4 (2,1)
	Ouvrier		0		1 (3,6)		0		1 (3,1)		1 (2,9)		0		0		3 (1,6)
	Autre		0		0		0		0		1 (2,9)		0		0		1 (0,5)
Nombre d'années sur le site	1-2 ans	20	4 (20,0)	28	13 (46,4)	21	3 (14,3)	31	6 (19,4)	34	4 (11,8)	26	3 (11,5)	25	5 (20,0)	185	38 (20,5)
	3-5 ans		8 (40,0)		6 (21,4)		8 (38,1)		5 (16,1)		6 (17,7)		17 (65,4)		8 (32,0)		58 (31,4)
	6-10 ans		4 (20,0)		3 (10,7)		4 (19,1)		3 (9,7)		10 (29,4)		3 (11,5)		8 (32,0)		35 (18,9)
	> 10 ans		4 (20,0)		6 (21,4)		6 (28,6)		17 (54,9)		14 (41,2)		3 (11,6)		4 (16,0)		54 (29,1)
Statut foncier	Emprunt	20	20 (100)	27	27 (100)	22	22 (100)	32	30 (93,8)	34	34 (100)	25	22 (88,0)	25	23 (92,0)	185	178 (96,2)
	Par don		0		0		0		2 (6,3)		0		3 (12,0)		0		5 (2,7)
	Locataire		0		0		0		0		0		0		2 (8,0)		2 (1,1)
Surface moyenne exploitée	40-500 m^2	20	7 (35,0)	28	9 (32,1)	20	9 (45,0)	27	5 (18,5)	33	5 (15,2)	24	4 (16,7)	25	6 (24,0)	177	45 (25,4)
	501-1000 m^2		1 (5,0)		6 (21,4)		6 (30,0)		7 (25,9)		10 (30,3)		4 (16,7)		5 (20,0)		39 (22,0)
	1001-2000 m^2		2 (10,0)		10 (35,7)		1 (5,0)		6 (22,2)		8 (24,2)		5 (20,8)		6 (24,0)		38 (21,5)
	> 2000 m^2		10 (50,0)		3 (10,7)		4 (20,0)		9 (33,3)		10 (30,3)		11 (45,8)		8 (32,0)		55 (31,1)
Systèmes de culture[b]	légumes fe+fl (1)	20	3 (15,0)	28	20 (71,4)	22	6 (27,3)	31	12 (38,7)	35	22 (62,9)	27	0	25	15 (60,0)	188	79 (42,0)
	lfr/lfe+lfl (2)		9 (45,0)		0		6 (27,3)		9 (29,0)		4 (11,4)		16 (59,3)		0		47 (25,0)
	lfr/lfe+lfl/lbu (3)		5 (25,0)		5 (7,1)		0		0		0		9 (33,3)		4 (16,0)		24 (12,8)
	autres combinat. (4)		3 (15,0)		6 (21,4)		10 (45,4)		5 (32,2)		9 (25,7)		2 (7,4)		6 (24,0)		38 (20,2)

[a]moyenne géométrique ; [b]Systèmes de culture : (1) légumes feuilles et fleurs ; (2) lég. fruits / lég. feuilles et fleurs ; (3) lég. fruits / lég. feuilles et fleurs / lég. tubercules et bulbes ; (4) autres combinaisons

La durée de présence du cultivateur sur le site varie entre un et 39 ans. La répartition des cultivateurs sur le nombre d'années sur place était à peu près stable, ce qui laisse conclure qu'une fois s'être lancé, ils persistent dans cette activité. La grande majorité des producteurs (94,3%) travaillent sur un seul site et presque tous empruntent le terrain. Concrètement, ce statut d'emprunt est basé sur un accord oral entre le propriétaire du territoire et le producteur. Les propriétaires des terrains dans notre enquête étaient des privés (zone 2), des sociétés (Air Afrique, zone 6), ou l'état (Agence de Télécoms de Côte d'Ivoire, zones 4 et 5, Compagnie Ivoirienne d'Electricité (CIE), zone 1.

Lors de nos passages en septembre / octobre 2004 et en mars 2005, 42,0% des cultivateurs avaient des systèmes de culture à légumes feuilles et fleurs (p. ex. salade, épinard et menthe). Un quart des planteurs combinait des légumes fruits (p. ex. gombo, aubergine locale et poivron) avec les légumes feuilles et fleurs, et la production combinée supplémentairement à celle des légumes bulbes (p. ex. oignon et poireau) était pratiquée par 12,8% des producteurs. Les cultures maraîchères sont accolées pendant toute l'année.

Figure 3.2 Jardins maraîchers à Port-Bouët ASECNA (zone 6), Abidjan en septembre 2004

Lors de notre enquête, les cultivateurs étaient priés de citer les problèmes principaux rencontrés sur le site. L'ensemble des réponses montre que les difficultés essentielles des maraîchers dans la ville d'Abidjan peuvent être imputées au caractère volatile du marché foncier et à l'absence de la reconnaissance officielle de l'agriculture urbaine comme activité économique, ainsi que l'occupation du sol par le gouvernement. Les problèmes liés à la santé sont à l'avant-dernière position, et ne constituent pas une contrainte importante pour l'activité agricole d'après les producteurs (Figure 3.3).

La préoccupation majeure des producteurs maraîchers est l'acquisition de terre cultivable et l'insécurité foncière. Le décret du 20 mars 1967, relatif à l'utilisation du territoire en Côte d'Ivoire, déclare que la terre appartient à celui qui la met en valeur, à condition que les droits d'exploitation soient registrés formellement (Heath 1993). Puisque l'accord d'utilisation pour le jardinage n'était pas clairement établi entre les deux partis dans les cas observés, le droit de présence sur le site pouvait se terminer d'un jour à l'autre pour le producteur. Débroussaillées par les premiers immigrés, les berges lagunaires ont été occupées progressivement par des successeurs. Ce processus de défrichement a été observé dans la zone 6 proche de l'aéroport international de Felix Houphouët-Boigny à la périphérie de la ville, lors de nos passages.

A la deuxième place se présentent les difficultés de la commercialisation des produits maraîchers. La plupart des entretiens avaient été conduits en septembre et octobre 2004, en période de transition de la saison pluvieuse à la saison sèche. Durant cette période, les cultures potagères prospèrent bien et suite à une offre abondante sur le marché, les prix baissent. Ce résultat pourrait prétendre donc un phénomène ponctuel ou saisonnier qui est lié au moment du passage des enquêteurs. Des travaux non-publiés du CSRS ont montré que la commercialisation était une contrainte majeure à la production maraîchère dans le domaine rural, et il serait intéressant d'évaluer la problématique réelle ou saisonnière de débouché pour les produits urbains. Il a été d'ailleurs observé dans de nombreux cas que les activités de la production et de la commercialisation étaient bien divisées par sexe au sein de la même famille: l'homme produit et l'épouse s'occupe de la vente au marché.

Les contraintes physiques, regroupant le climat (p. ex. les fortes pluies, les inondations et le manque d'eau en saison sèche) et la nature des sols sableux (la porosité et la non-fertilité), ainsi que les risques phytosanitaires (l'état phytosanitaire des cultures et les dégâts par des insectes, nématodes et oiseaux) apparaissent avant les difficultés financières dans notre classement des problèmes vécus. Les aspects de « finances » et d'« équipements techniques » (aménagements techniques pour maîtriser l'eau) relèvent l'absence des institutions agricoles facilitant des micro-crédits et la formation spécifique dans le cadre du maraîchage. Il en était de même pour les intrants et outillages agricoles et les produits phytosanitaires. Pendant nos enquêtes, seulement 2 sur 7 zones maraîchères étaient encadrées par des agents de l'ANADER.

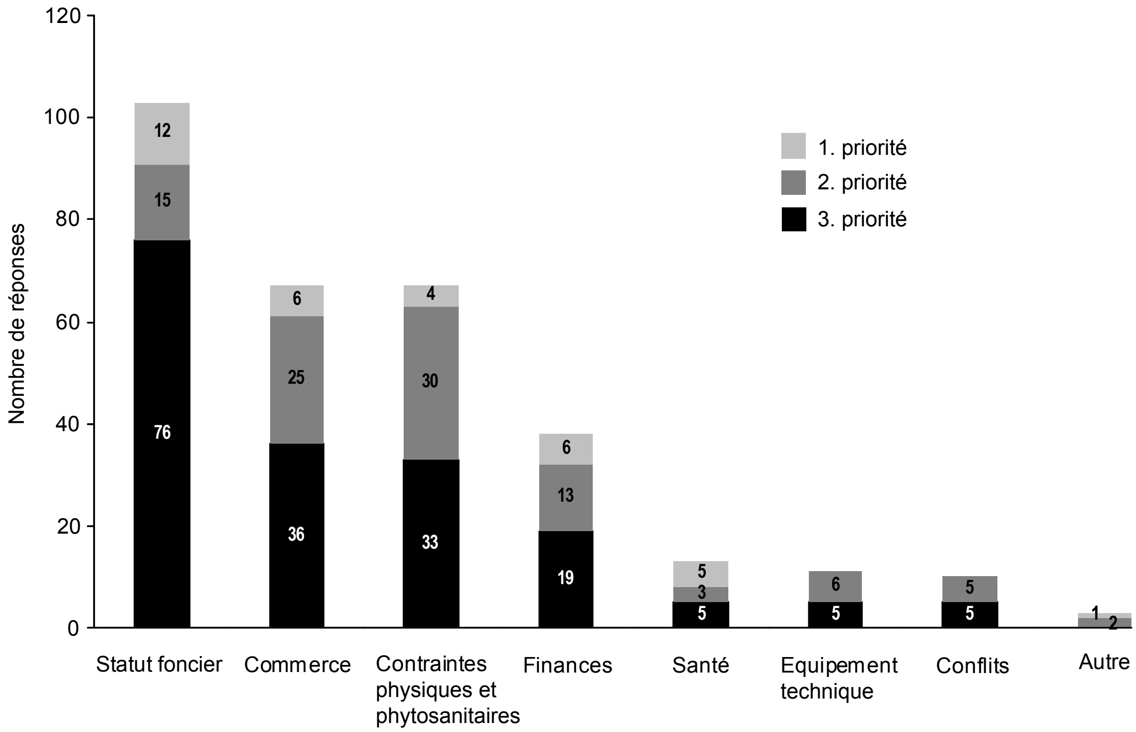

Figure 3.3 Difficultés principales par rapport à l'activité du maraîchage

Les problèmes liées à la santé figurent en dernière priorité, avec les conflits entre les différents groupes d'intérêt (force de défense et de sécurité, agents municipaux, cultivateurs, commerçants, propriétaires terriens), les problèmes d'ordures et les vols des produits sur les sites. Un sondage plus approfondi dans le même questionnaire sur les maladies apparues dans les ménages pendant les dernières 4 semaines montre cependant une image différente : parmi les maladies mentionnées, la réponse « palu » (paludisme) est la plus fréquente (figure 3.4). Au total deux tiers (66,0%) de l'ensemble des zones rapportent des cas de paludisme. Nous pensons que la haute morbidité pourrait être due à la notion locale du paludisme, qui comprend en même temps d'autres symptômes de maladie (Granado et al. 2006). En plus, des accès palustres sont souvent auto-diagnostiqués et auto-traités avec des indigénats pour éviter les complications qu'une visite dans un centre de santé pourrait entraîner (absence du travail, réunir les frais de consultation et traitement et autre). Il a été récemment estimé que l'auto traitement des crises paludéennes dans les zones urbaines est en moyenne à 50% (Bates *et al.* 2004). Des recherches dans ce domaine sont en cours, visant à mieux comprendre les expériences et significations locales du paludisme dans des quartiers d'Abidjan.

Les douleurs musculaires, articulaires et lombaires et la fatigue ressentie peuvent être regroupées comme « symptômes professionnels » attribués à ce travail accaparant sous des conditions climatiques dures. En plus, ces systèmes de culture intensifs exigent une présence quotidienne ; par exemple l'arrosage des plantes doit s'effectuer à des intervalles de temps très courtes, surtout pendant la saison sèche et les jours ensoleillés. Les maladies digestives et diarrhéiques, ainsi que les maladies respiratoires sont mentionnées beaucoup moins fréquemment que « palu » et « douleurs articulaires ». Ce fait pourrait être dû à la conception de « maladie » par les cultivateurs : les symptômes sont discernés comme « maladie » à partir du moment où les douleurs se font sensiblement remarquer et empêchent de travailler.

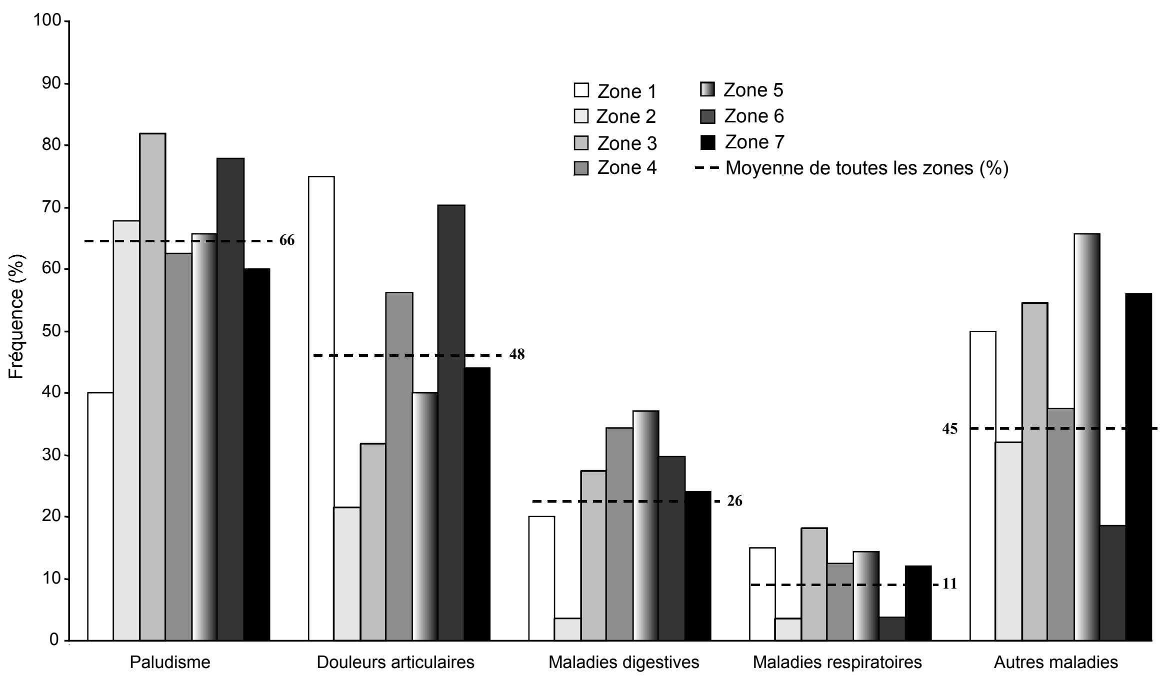

Figure 3.4 Maladies perçues par les cultivateurs

Les résultats parasitologiques portant sur les infections paludéennes et parasitoses intestinales sont résumés au Tableau 3-2. A travers toutes les zones maraîchères, un quart (24,3%) de tous les participants étaient infectés par *Plasmodium* (90 cas par *P. falciparum* et 7 cas par *P. ovale*).

Tableau 3-2 Nombre (%) des personnes infectées par *S. mansoni*, géohelminths, protozoaires intestinales, et *Plasmodium* spp., stratifié par ménages cultivateurs (n = 121) et non-cultivateurs (n = 20) dans la ville d'Abidjan, Côte d'Ivoire

Parasite	Prévalence générale No. (%)	Personnes des ménages cultivateurs No. (%)	Personnes des ménages non-cultivateurs No. (%)	*P*-valeur[a] No. (%)
	(n = 426)	(n = 364)	(n = 62)	
Schistosoma mansoni	6 (1.4)	5 (1.4)	1 (1.6)	0.613[b]
Géohelminths				
Ancylostomes	66 (15.5)	63 (17.3)	3 (4.8)	0.012[b]
Trichuris trichiura	179 (42.0)	155 (42.6)	24 (38.7)	0.568
Ascaris lumbricoides	53 (12.4)	47 (12.9)	6 (9.7)	0.476
Protozoaires intestinaux	(n = 364)	(n = 316)	(n = 48)	
Entamoeba coli	126 (34.6)	109 (34.5)	17 (35.4)	0.900
Entaemoeba histolytica/E. dispar	38 (10.4)	36 (11.4)	2 (4.2)	0.201[b]
Blastocystis hominis	119 (32.7)	107 (33.9)	12 (25.0)	0.223
Entamoeba hartmanni	21 (5.8)	20 (6.3)	1 (2.1)	0.240[b]
Iodamoeba buetschlii	41 (11.3)	37 (11.7)	4 (8.3)	0.343[b]
Chilomastix mesnili	20 (5.5)	16 (5.1)	4 (8.3)	0.317[b]
Endolimax nana	103 (28.3)	92 (29.1)	11 (22.9)	0.374
Giardia duodenalis	30 (8.2)	24 (7.6)	6 (12.5)	0.250
Malaria	(n = 427)	(n = 370)	(n = 57)	
Plasmodium falciparum	107 (25.1)	90 (24.3)	17 (29.8)	0.372
Plasmodium malariae	8 (1.9)	7 (1.9)	1 (1.8)	0.943[b]

[a] *P*-valeur basé sur χ^2-test ; [b] *P*-Valeur basé sur le test de Fisher's exact test

Le numéro d'individus diffère entre ceux qui avaient donné des échantillons des selles et ceux qui s'étaient présentés pour le test de frottis sanguin/goutte épaisse (test de présence de *Plasmodium* dans le sang)

La répartition de la prévalence parasitémique varie considérablement entre les sites, passant de 8,3% (zone 2) à 52,7% (zone 7). Nous assumons que le risque de transmission ne soit pas fortement lié aux activités agricoles maraîchères, puisque les travaux champêtres se font habituellement entre 8 et 18 heures, et les moustiques de l'espèce *Anopheles*, vecteur du paludisme, sont actifs surtout entre 22 heures la nuit et 6 heures du matin. Toujours dans cette ligne de réflexion, un rôle plus important reviendrait à la distance entre les habitations et les gîtes larvaires productifs, à l'ensemble de l'environnement que nous n'avons pas caractérisé en détail dans l'article présent, et aux mesures protectrices et préventives personnelles comme l'habitation et les moustiquaires imprégnées. Ces aspects ont été enquêtés dans une étude récente sur le paludisme urbain et des productions irriguées dans la ville d'Accra au Ghana (Klinkenberg *et al.* 2005). Nous sommes en train d'étudier la question de l'implication de l'agriculture urbaine et son entourage physique dans la prolifération des gîtes larvaires productifs dans deux de différentes tailles en Côte d'Ivoire.

Concernant les parasites intestinaux, les infections de *T. trichiura* sont les plus fréquentes ; 42,6% des individus examinés sont porteurs de *T. trichiura*. Ce parasite est transmis par plusieurs voies : par la consommation d'aliments crus (p. ex. fruits et légumes), à travers les doigts, l'eau ou les sols infectés (Utzinger & Keiser 2004). Les prévalences dans les différentes zones varient entre 25,5 (zone 7) et 53,2% (zone 1). Alors que les ancylostomes se contaminent par les sols et entrent par les mains et pieds (Hotez *et al.* 2004), *A. lumbricoides* est transmis par les mêmes voies que *T. trichiura*. Les ancylostomes et *A. lumbricoides* sont moins fréquents (17,3% et 12,9%, respectivement au total). La zone 2 était la plus affectée par les ancylostomes (46,2%) et la zone 6 par *A. lumbricoides* (28,9%). Les quelques cas de bilharziose intestinale due à *S. mansoni* ont été soupçonnés d'être importés.
Des discussions informelles ont dévoilé qu'il y avait des campagnes de déparasitage de vers intestinaux par des organisations non-gouvernementales privées, ce qui pourrait expliquer les taux relativement faibles des ancylostomes. Une limite de notre étude exploratoire est la collecte d'un seul échantillon de selles par personne. En outre, nous n'avons pas inclus dans nos enquêtes une question sur un déparasitage récent, et nous n'avons non plus analysé les prévalences parasitaires par catégories d'age. Souvent, les enfants étaient présents sur le site pour soutenir leurs parents, surtout pendant les jours de congé et les vacances. Malgré ces restrictions méthodologiques, la prévalence parasitaire nous semble toujours assez haute et nous estimons que la prévalence réelle est encore considérablement plus élevée.

Nous réitérons que la perception des maladies digestives diffère de la perception du paludisme, surtout par rapport aux effets secondaires de maladie. Souvent, les maladies intestinales sont accompagnées de symptômes latents et donc sous-estimés, et deuxièmement des maux de ventre ou une diarrhée n'empêchent pas forcément de travailler. La conscience d'être « souffrant de vers » n'existe pas ou est peu développée.

La distribution inhomogène des prévalences parasitaires indique la spécificité de certaines zones de production à des affectations. Par exemple, un foyer d'*A. lumbricoides* semble être lié à la zone 6, tandis que la prévalence paludéenne est très élevée en zone 7. Ces points focaux par zone maraîchère indiquent que des conditions particulières peuvent favoriser les pré-dispositions de la transmission de ces parasites. Tenu compte de la complexité de la dynamique de transmission, qui peut s'effectuer à la localité de la résidence comme du travail pour certaines affectations, ainsi que la multitude des facteurs environnementaux, sociaux et sanitaires qui y interviennent, des analyses plus approfondies seront nécessaires afin d'élucider plus clairement le rôle de l'agriculture urbaine dans la transmission des maladies parasitaires. Le présent travail permet d'encourager des études dans ce sens, leur donne une base solide et contextuelle, et justifie ce travail onéreux sur la base de la morbidité des producteurs et les membres de leur ménage démontrés ici.

3.5 Conclusion

Trois résultats peuvent être retenus de notre étude ciblée sur les perceptions des maladies et la présence des parasitoses humaines dans les zones maraîchères à Abidjan. Premièrement, les préoccupations de santé par les maraîchers sont refoulés par d'autres difficultés et occupent une position secondaire. Deuxièmement, « palu » (paludisme) et les maladies digestives ne sont pas perçus de la même façon ; les dernières sont probablement sous-estimées relativement au paludisme à cause de leur nature souvent subliminale. Troisièmement, malgré les limitations liées à la représentativité de notre prélèvement, nous avons constaté néanmoins que la prévalence paludéenne et des vers intestinaux sont importantes: un quart (24.3%) des participants sont porteurs de *Plasmodium*, agent infectieux du paludisme, et 64.7% étaient infectés de deux ou plusieurs parasites intestinaux. La prévalence paludéenne et des parasites intestinaux semble être de nature focale parce qu'elle variait nettement entre les différentes zones de production.

La reconnaissance officielle de l'activité maraîchère dans la ville d'Abidjan, dont son absence est ressorti dans les préoccupations des producteurs, pourrait contribuer à stabiliser les conditions de vie de ce groupe marginalisée et leur apporter une base pour gérer leur vulnérabilité face aux difficultés prononcées, y compris sanitaires. Cette reconnaissance devrait être accompagnée d'abord par des mesures pratiques au niveau du règlement foncier, mais aussi par la mise en place des structures agricoles de consultation (formation, micro-crédits). Ces mesures pourraient aussi être accompagnées par des stratégies de protection sanitaire (éducation sanitaire et moustiquaires imprégnées) et de contrôle (réduction des gîtes larvaire potentiels).

3.6 Support financier

Cette étude pouvait être réalisée grâce et dans le cadre du programme « Swiss National Centre of Competence in Research / NCCR North-South», implémenté financièrement par le Fonds National Suisse de la Recherche Scientifique.

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4. Le réseau social des maraîchers à Abidjan agit sur la perception des préoccupations et des risques sanitaires liés à l'eau

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L'article présent a été publié dans:
VertigO Hors Série 3, Décembre 2006

4.1 Résumé

L'objectif de la présente étude conduite dans des zones de production maraîchère d'Abidjan, Côte d'Ivoire, était d'analyser les problèmes principaux des cultivateurs; leur perceptions des maladies et des risques sanitaires et la corrélation entre les risques sanitaires et le statut socio-économique des ménages ainsi que la cohésion sociale dans les communautés maraîchères. Les problèmes principaux sont l'insécurité foncière et de difficultés de commercialisation. Les préoccupations sanitaires sont la fatigue et l'insalubrité. En l'absence d'une éducation sanitaire fondée et des interventions localement adaptées, les cultivateurs n'accordent pas une attention particulière à la prévention des risques sanitaires. Le support technique, en concordance avec l'éducation et la communication de la prévention des risques sanitaires, promettent une augmentation de la productivité et une amélioration des moyens de subsistance des ménages cultivateurs à Abidjan.

Mots clés

Agriculture urbaine, communautés maraîchères, Côte d'Ivoire, risques sanitaires, cohésion sociale

4.2 Summary

The purpose of the present study, carried out in market garden settings of Abidjan, Côte d'Ivoire, was to investigate the farmers' main problems, their perceptions of illnesses and health risks, and how the latter are associated with the socio-economic status of the households, as well as the social cohesion of farming communities. The main problems identified include insecure land tenure and the paucity of bringing farm products to the local markets. Tiredness and contaminated environment were the major health preoccupations. In the absence of sound health education and locally-adapted interventions, urban farmers do not attach sufficient importance to health risk prevention. We suggest that technical support, in concert with information, education and communication on health risk prevention, holds promise to enhance productivity and hence improve the livelihoods of urban farmers in Abidjan.

Keywords

Urban agriculture, farming communities, Côte d'Ivoire, health risks perception, social cohesion

4.3 Contexte et cadre de recherche

L'agriculture urbaine a une longue tradition dans les villes en Afrique sub-Saharienne (Winters 1983). Une reprise de l'agriculture urbaine dans les zones urbanisées en Afrique de l'Ouest depuis les dernières deux décennies a été observée suite à l'urbanisation rapide et la stagnation économique (Asomani-Boateng 2002; Cissé *et al.* 2005; Zallé 1999). Les potentialités sont l'approvisionnement des produits frais des populations urbaines et la création d'emploi (Dongmo et al. 2005). Sur le plan politique cependant, la compétition sur le foncier urbain et certains risques pour la santé publique comme par exemple la contamination des pathogènes à travers les eaux usées employées pour l'irrigation des maraîchers (Cissé et al. 2002) ont représenté des contraintes qui ont reculé la majorité des ministères de l'urbanisme de repousser des actions législatives pour la garantie de sécurité foncière pour l'agriculture urbaine. A Abidjan, la capitale économique de la Côte d'Ivoire et comptant trois millions d'habitants en 1998 (INS 1998), de nombreux sites de maraîchage se sont développés pendant les dernières quatre décennies, surtout dans les berges lagunaires sur les territoires de l'Etat et des sociétés privées, toutefois en l'absence de la reconnaissance des autorités municipales (AGRISUD 1999).

L'objectif principal de l'étude présentée ici était d'identifier les problèmes principaux des ménages cultivateurs qui font le maraîchage, et leurs perceptions des risques sanitaires liées à l'eau. En outre nous avons analysé des associations entre les difficultés perçues par les ménages cultivateurs au travail et à domicile et leur statut socio-économique, ainsi que la cohésion sociale des maraîchers au niveau communautaire où chaque zone maraîchère forme une entité sociale.

Dans une première étape, nous avons évalué le profil démographique de 189 cultivateurs et conduit des examens parasitologiques dans sept zones maraîchères à Abidjan, centre économique de la Côte d'Ivoire, par administration d'un questionnaire. Les prévalences paludéennes et des vers intestinaux ressortis étaient importantes : le taux des porteurs de *Plasmodium*, agent infectieux du paludisme, était à 24,3%, et 64,7% des personnes examinées étaient infectés d'un ou plusieurs vers intestinaux. La mise en place d'un cadre institutionnel pour l'agriculture urbaine est indiqué ainsi que l'élaboration de stratégies de contrôle et de protection face aux risques sanitaires (Matthys et al, working paper).

Dans la présente étude, nous supposons que la perception des problèmes par les maraîchers est influencée non seulement par les conditions socio-économiques des ménages, mais aussi par la cohésion sociale dans une zone maraîchère qui pourrait jouer un rôle dans la gestion des difficultés rencontrées sur place. Nos données sont examinées et mises en contexte de l'« asset vulnerability framework » présentée par Moser (1998). D'après ce concept, la vulnérabilité dépend des « capitaux » groupées sous les cinq termes suivants: (i) travail, (ii) capital humain, (iii) capitaux productifs (« housing »), (vi) relations au niveau du ménage, et (v) capital social (Mani 2004; Moser 1998). Nous avons comparé les stratégies de mobilisation des « capitaux » de Moser avec celles des maraîchers à Abidjan. Les capitaux humain (ii), productif (iii) et social (v) sont discutés globalement.

4.4 Matériel et méthodologie

Zone d'étude

La zone d'étude comprend sept zones maraîchères de la ville d'Abidjan (Figure 4.1). Les zones se trouvent dans les communes de Koumassi (zones 1 et 2), Marcory (zones 3-5), Port-Bouët (zone 6) et Cocody (zone 7). Toutes les zones occupent des berges lagunaires, à l'exception de la zone 6. Les terrains cultivables sont empruntés soit à l'état, soit à des sociétés ou des privés. Les cultures produites sont des feuilles et légumes (p. ex. salade, épinard et menthe), légumes-fruits (p. ex. gombo, aubergine et poivron) et légumes-bulbes (p. ex. oignon et poireau).

Le profil démographique et socio-économique et les conditions de vie des ménages de cultivateurs diffèrent peu d'une zone à l'autre. Il s'agit de ménages de nationalité « non ivoirienne », originaires du Burkina Faso et en majorité musulmans (88,8%). La plupart des cultivateurs sont mariés (82,0%), non-alphabétisés (79,8%), exerçant le maraîchage dans 68,8% des cas comme seule activité professionnelle (Matthys et al., working paper).

Strates de cohésion sociale

Nous avons regroupé les sept zones de production en trois strates de cohésion sociale comme suivent:

- les zones représentées par un délégué des producteurs et un agent d'une structure agricole de l' « Agence Nationale d'Appui au Développement Rural » (ANADER) (zones 6 et 7) ;
- les zones avec uniquement un délégué des producteurs (zones 1, 4 et 5) ; et
- les zones sans délégué et sans structure agricole (zones 2 et 3).

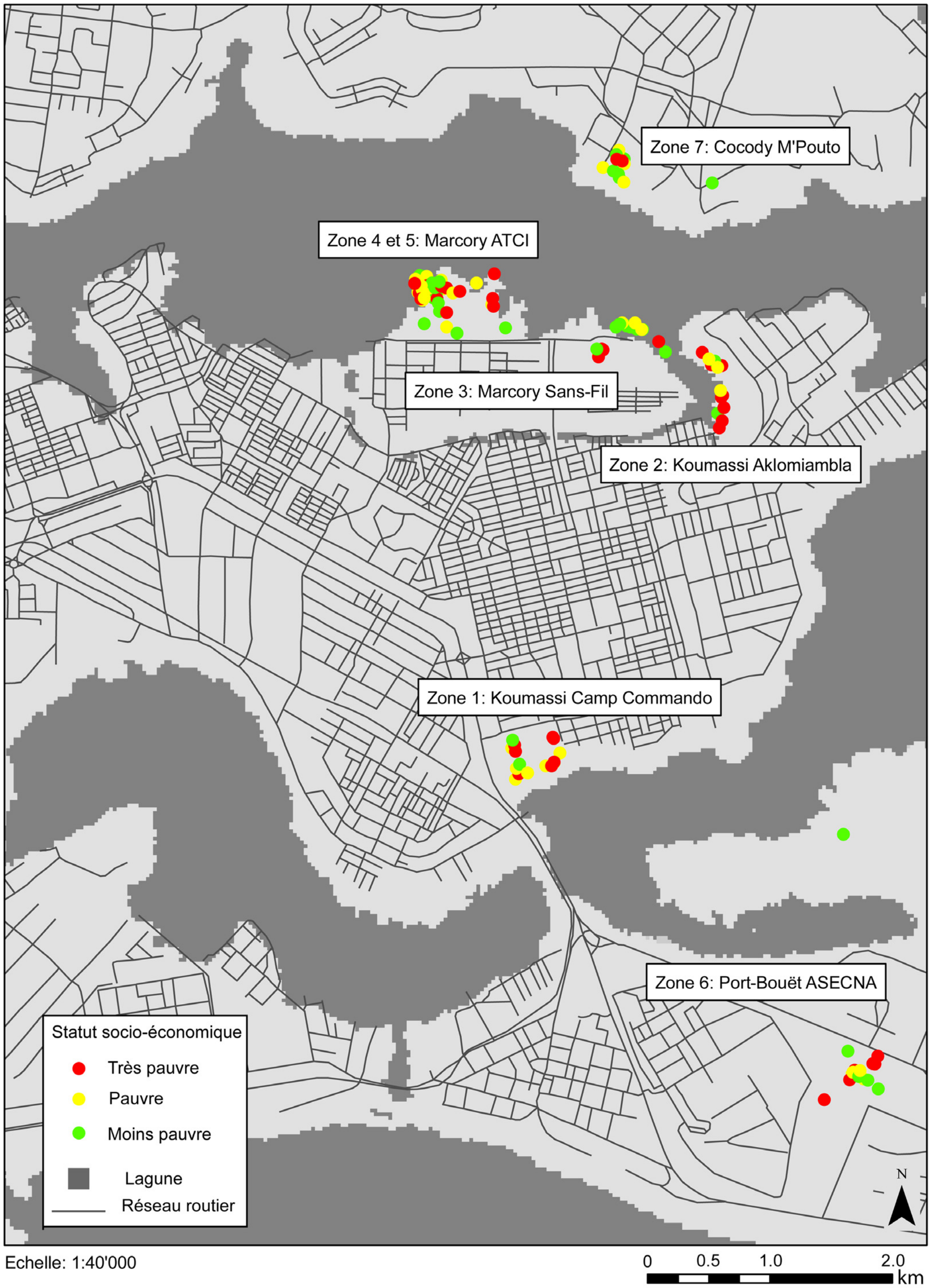
Questionnaires et groupes de discussion

Deux questionnaires concernant les activités agricoles et la situation socio-économique et sanitaire ont été menés entre octobre 2004 et mai 2005. 189 cultivateurs ont été interrogés sur l'agriculture en octobre 2004. 118 cultivateurs ré-identifiés en mai 2005 ont participé à un sondage sur la situation socio-économique et sanitaire. Les questionnaires comportaient des sections quantitatives et qualitatives et étaient adressés auprès les ménages après un pré-test. Les producteurs étaient priés de citer les trois difficultés majeures rencontrées sur leurs sites de travail et au domicile. Leurs déclarations ont été ensuite regroupées dans les catégories de problèmes suivantes : (i) sur le site de travail (statut foncier, commerce, contraintes physiques et phytosanitaires, finances, santé, équipement technique, conflits et autre) et (ii) à domicile (finances et économie, sécurité et stabilité politique du pays, alimentation, santé et autre).

Les groupes de discussion sur la perception des risques sanitaires et les stratégies de prévention ont été menées avec les maraîchers des sept zones en septembre 2004. Le guide d'entretien a été pré-testé dans une zone supplémentaire. La méthodologie des groupes de discussion permet de comprendre les connaissances, attitudes, pratiques et perceptions des groupes ciblés (Dawson et al. 1995), dans le cas présent des cultivateurs par rapport aux risques sanitaires liés aux activités agricoles. L'équipe qui a conduit les groupes de discussion était composée d'un modérateur et d'un observateur. Le nombre des participants variait de six à neuf personnes, en présence du délégué de la zone dans la plupart des groupes de discussion menées. Dans une zone uniquement, le groupe était composé d'hommes et de femmes. Dans les autres zones seulement des hommes prenaient part. Les discussions ont été enregistrées par l'observateur à l'aide d'un appareil d'enregistrement. Le modérateur, qui dirigeait les discussions, a pris des notes. Les transcriptions ont été effectuées conjointement par le modérateur et l'observateur et enregistrées en fichiers Word pour les analyses.

Gestion des données et analyses statistiques

Les données des questionnaires ont été entrés en double sur le logiciel EpiData (version 3.1, EpiData Association, Odense, Denmark). Les analyses statistiques ont été effectuées dans le logiciel Stata (version 9, Stata Corporation, College Station, TX, USA). Le statut socio-



Source: Image Landsat 2000, Châtelain C.,
Conservatoire et Jardin Botaniques, Université de Genève
Auteur: Barbara Matthys
Edition: Novembre 2006

Figure 4.1 Les sept zones maraîchères sélectionnées dans la ville d'Abidjan et la répartition du statut socio-économique des cultivateurs économique des ménages cultivateurs a été calculé en utilisant des caractéristiques de propriété (bicyclette, cellulaire, moustiquaire, radio, réfrigérateur, téléviseur, ventilateur et magnétoscope) et de l'habitation (nombre de chambres, sources d'énergie pour cuisiner, statut de logement) selon l'analyse des facteurs principaux (Filmer & Pritchett 2001). La méthodologie et les procédures appliquées sont décrites dans (Gwatkin et al. 2000) et ont été adaptées lors d'un travail précédant dans la zone rurale de la région de Man à l'Ouest de la Côte d'Ivoire (Raso et al. 2005). Les ménages étudiés ont été regroupés dans les trois catégories suivantes : (i) plus pauvres, (ii) pauvres, et (iii) moins pauvres. Le nombre des catégories, contrairement aux quintilles habituelles, se réfère au profil homogène du statut socio-économique. Le test de χ^2 a été appliqué afin d'identifier les différences significatives entre les problèmes principaux sur le site de travail et à domicile, en fonction du statut socio-économique et des trois strates de cohésion sociale. Le test de Kruskal-Wallis a permis d'analyser les différences des priorités des problèmes entre les trois strates.

4.5 Résultats

Préoccupations principales

Les difficultés principales rencontrées sur les sites de travail de 189 ménages interrogés sont détaillées ailleurs (Matthys et al., working paper). En bref, les problèmes majeurs étaient (i) l'accès à la terre cultivable, (ii) l'insécurité foncière (disparition des surfaces cultivables au profit de l'immobilier), et (iii) les problèmes de commercialisation des produits maraîchers (fluctuation des prix). Les difficultés majeures au domicile étaient (i) de nature financière et économique, (ii) la commercialisation, et (iii) la sécurité personnelle. En outre étaient avancés les problèmes d'alimentation et de santé, placés en dernière position (Figure 4.2).

Les problèmes financiers et économiques incluent le chômage, la baisse du pouvoir d'achat, et la prise en charge des frais d'habitation (le loyer, l'eau et l'électricité). Les participants à l'enquête ont clairement affirmé la dégradation de la sécurité dû à la situation socio-politique actuelle du pays, qui freine aussi les activités économiques. Ils décrivent l'insécurité générale à travers les expériences quotidiennes de vols, d'actes de vandalisme et de nombreux contrôles par les forces de l'ordre. Les impasses liées à l'alimentation se manifestent dans le sens de ne pas pouvoir assurer des repas réguliers.

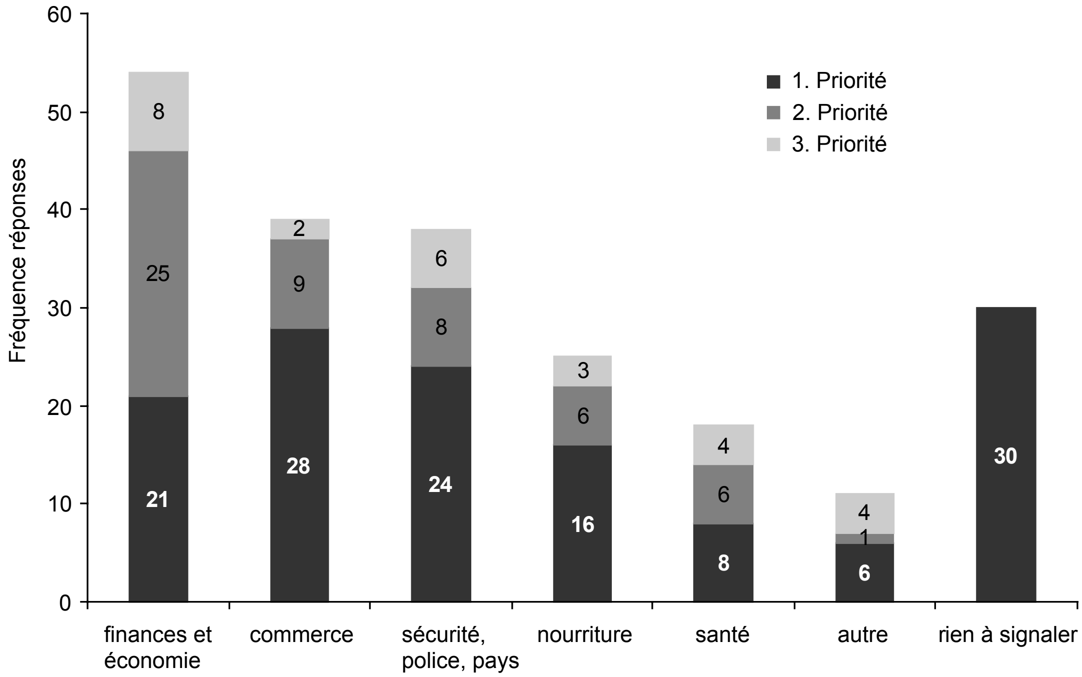


Figure 4.2 Difficultés aperçues à domicile par les maraîchères d'Abidjan

La conscience sur l'entourage de la zone maraîchère et les risques des maladies perçues

Les problèmes sanitaires figurent à la fin des préoccupations, et saisissent moins le statut sanitaire ou la nature des maladies, mais plutôt les soucis de ne pouvoir se procurer des soins. Ce fait n'est pas étonnant, supposant que dans la lutte quotidienne de survie, les problèmes de santé émergent au cas d'urgence. Pourtant, les groupes de discussion à propos des perceptions des maladies et risques sanitaires dans le contexte du maraîchage montrent bien la conscience des risques sanitaires.

Les cultivateurs sont préoccupés par les problèmes de santé liés à l'état de propreté de l'entourage. L'insalubrité est retenue comme cause des maladies contractées sur le site de travail par la présence des dépôts d'ordures ménagères du quartier et le « péril fécal », entraînant la prolifération des mouches. *« Le site est un ancien dépotoir. Les riverains continuent de déposer des déchets dans le jardin. En plus, les gens y défèquent ».* Le contact permanent avec ce milieu les rendrait vulnérable au point que l'organisme serait fragilisé par les attaques d'agents pathogènes, ignorés car non-viables. Les mots cités en langue locale pour désigner ces maladies expriment l'état insalubre de la zone : « *croussa croussa* » en Dioula signifie « la gale » et d'autres sortes de démangeaison du corps, *« ding ding »* en Bissanga sont expliqués par l'ensemble de petites maladies et des maux qu'on contracte quand on plonge les membres de corps régulièrement dans l'eau « sale ». Les observations d'une étude conduite avec les maraîchers de Ouagadougou, Burkina Faso, montrent l'absence d'un lien entre les risques sanitaires et l'environnement dégradée (Cissé 1997). Les cultivateurs ont une notion nette de la qualité de l'eau : *« Lorsqu'on ne voit pas le fond du contenant d'eau, c'est que cette eau est sale. Quand on peut voir ce fond, c'est que c'est propre ». «Un puits peut donner une bonne eau si on en tire du sable. Si on rencontre des morceaux de tissus, de pagne, de fer et des sachets, cette eau est de mauvaise qualité et non consommable, autrement dit un risque pour la santé ».*

Maladies professionnelles et conceptions sur la maladie et la mort

Les maladies auxquelles les cultivateurs disent être exposés sont mentionnées souvent en associant « douleur » à la partie touchée pour signifier que ces maux sont liés au corps. Cités comme « maladies » sont la fatigue générale ; les douleurs musculaires, articulaires et lombaires ; les maux de tête et de ventre ; les blessures par les objets piquants ou coupants ; les pieds d'athlète ; le « palu » ; le choléra ; et les vers. Selon eux, la fatigue générale, dû au travail physique intense qui nécessite beaucoup d'énergie, entraîne d'autres maladies : *« Seule la fatigue due aux travaux sans repos est cause de palu, maux de tête, de dos ».*

Des réflexions spécifiques sur les maladies relèvent que les producteurs refusent l'idée selon laquelle il existe des maladies spécifiques aux jardiniers. Ils soutiennent que toutes les activités professionnelles représentent des risques. *« Il n'y a pas de maladies réservées aux jardiniers. Nous sommes victimes des mêmes maladies que les autres qui exercent un métier ailleurs ».* La maladie et la mort ne proviendraient pas seulement de l'environnement des jardiniers, elles seraient le fait du destin et de la « *volonté de Dieu* » qui *« programme la vie et la mort de l'homme ». « Il y a des gens qui font le jardin et qui guérissent facilement des maux de dos, de reins comme s'ils ne se seraient jamais contractés. Par contre, d'autres personnes meurent même les premiers jours de ces maux».*

Contamination d'autres membres de famille

Les idées sur les risques de contamination des membres de ménages par ceux qui travaillent dans les maraîchers divergent. Les uns expliquent que la contagion serait liée plutôt à la nature de l'homme qu'à la présence dans le jardin. *« Ces maladies s'attaquent aux membres de nos familles pas parce qu'ils viennent au champ aussi, mais parce qu'ils sont des hommes comme nous. Même les gens qui ne sont pas membres de notre famille et avec qui nous n'avons aucune relation souffrent des mêmes maladies que nous ».* Cette absence de conscience de risque de contamination est confirmé à travers les comportements observés à Ouagadougou (Cissé 1997).

D'autres soutiennent une association entre la présence régulière sur le site et un risque de contamination élevé. *« Ces maladies se contractent spécifiquement sur le lieu de travail et s'attaquent à ceux qui font le jardinage; comme c'est le cas de cet étudiant venu passer les vacances chez ses parents et qui les aidait ici »*. Mentionné est aussi la non-contamination par l'absence des membres de famille dans la zone : *« Ici, à aucun moment un enfant est venu rendre visite aux parents encore moins les membres de sa famille. Les enfants passent leur temps à l'école. Car il faut donner toutes les chances de réussir à l'école pour ne pas connaître les mêmes sorts que les parents, c'est-à-dire, se retrouver sur jardin d'où on ne rapporte rien »*.

Conscience des risques sanitaires liés à l'eau, modes de prévention

Les agriculteurs sont conscients des risques liés à l'eau, mais ils déclarent de ne pas savoir comment y éviter le contact permanent. *« Lorsqu'on soulève l'arrosoir, l'eau ruisselle sur tout le corps ». « Même quand on porte des bottes on n'y peut rien dans la mesure où le niveau de l'eau dans le puits dépasse les genoux ».*

La majorité des cultivateurs affirme ne pas boire l'eau d'arrosage par précaution. *« Même si cette eau semble propre, on ne peut le boire ».* Elle serait souillée par les produits phytosanitaires, *« des sortes de poisons qui tuent les insectes. La preuve est que les crabes des lagunes fuient les lieux de crainte de mourir au contact de ces produits »*. Quelques uns justifient leur abstention de consommer l'eau de puits d'arrosage par le désenclavement des espaces cultivées qui permet l'accès des vendeuses ambulantes à vendre l'eau de robinet en sachets à coût supportable. D'autres emportent l'eau du ménage dans des bidons.

Il est pourtant expliqué que l'eau des puits peut être utilisée pour l'arrosage des cultures sans effet négatif sur les produits, à condition qu'ils soient désinfectés à l'eau de javel avant la consommation. Par contre, ils se lavent dans ces puits les mains et pieds et prennent des bains. La maintenance de la propreté des puits d'arrosage est effectuée en les « curant » régulièrement. Il s'agit de *« débarrasser un endroit de toutes sortes de choses pouvant rendre sale l'eau du puits »* et *« d'enlever le sable et l'eau afin d'assainir le puits »*, plusieurs fois par an. Après cette action, l'eau serait *« propre à telle enseigne que si personne n'y entre avec ses pieds souillés par les produits phytosanitaires, elle est consommable »*. Toutefois, les perceptions de la qualité de l'eau par des maraîchers à Ouagadougou et leurs pratiques agricoles et hygiéniques sur les sites pourraient favoriser les risques de contamination des maladies parasitaires (Ouedraogo *et al.* 1999).

Attitudes et pratiques en cas de maladie : Auto-traitement, recherche d'aide et réseau social

Les cultivateurs pratiquent l'automédication et des méthodes de soins curatifs à faible coût tels que la pharmacopée et la pharmacie « par terre » (médicaments vendus dans les rues à bas prix). Ils expliquent ce choix par le manque de moyens financiers et par l'absence d'assurance maladie pour se soigner dans de bonnes conditions. Convaincus que leurs maladies sont liées aux travaux intensifs, ils cherchent alors à combattre la fatigue avec des extraits de bouillon de mélange des feuilles, p. ex. de « kinkéliba» et de citronnelle, et par la prise de somnifères. Les racines de l'arbre pantropical *Cassia occidentalis*, « Kinkéliba », sont employées comme antipaludiques et fébrifuges (cf. *http://www.enda.sn/plantesmed/cassiaocci.html*). *« Lorsqu'on sent la fatigue, on prend des comprimés pour bien dormir. Mais aussi par manque de moyens on prépare un mélange de feuilles de bananiers, de papayers pour boire et se laver avec l'eau recueillie trois fois par jour, ce qui réduit la fatigue et protège de la maladie ».*

En cas de maladie, les médicaments ordonnées sont achetés en fonction de la capacité financière : *« Ceux qui n'ont pas tous les frais des soins achètent par étape, ceux qui en ont en une seule fois »*. Le manque de moyens pour assurer les frais des médicaments est souvent cité: *« Il nous arrive de garder l'ordonnance et de la payer partiellement en s'endettant. En cas de maladie, ceux qui ont les moyens vont consulter le médecin. Ceux qui n'en ont pas restent à la maison et utilisent la pharmacopée africaine ».* Le fonctionnement du réseau social dans les communautés maraîchères apparaît en cas de maladie sévère. Les bien-portants manifestent leur solidarité envers le malade en faisant son travail en groupe de sorte qu'il puisse s'occuper de sa famille avec les revenus de sa récolte.

Le statut socio-économique des maraîchers

Tableau 4-1 montre le statut socio-économique de 118 ménages cultivateurs inclus dans l'analyse, et les caractéristiques de propriété et de l'habitation à l'aide desquels le statut socio-économique a été calculé. La première composante explique 20.2% de la variabilité. Les paramètres étaient standardisés pour déterminer leurs scores. Les ménages possédant un réfrigérateur ont les scores les plus élevés (1,17), suivi par les ménages avec une vidéo (0,84). Les scores les plus bas ont été attribués aux cultivateurs qui ne disposent pas d'outils de cuisine (qui mangent dans des kiosques) (-0,61), suivi par les ménages sans radio (-0,57). Les taux des « capitaux » ont été calculés par classe socio-économique. Par exemple, 78,0% de tous les ménages possèdent un ventilateur, dont 58,5% parmi les plus pauvres et 92,1% parmi les moins pauvres.

Tableau 4-1 Statut socio-économique des ménages cultivateurs à Abidjan

Asset variable	**Tertiles (%)**				
	Les plus pauvres	**Pauvres**	**Les moins pauvres**	**Total**	**Scoring coefficient**
	(n = 41)	(n = 39)	(n = 38)	(n = 118)	
Ventilateur	58.5	84.6	92.1	78.0	0.2710
Radio	46.3	71.8	100.0	72.0	0.3585
Télévision	22.0	79.5	94.7	64.4	0.4079
Bicyclette	41.5	69.2	73.7	61.0	0.1705
Cellulaire	7.3	15.4	73.7	31.4	0.3986
Moustiquaire (non imprégné)	7.3	15.4	34.2	18.6	0.2538
Magnétoscope	0.0	7.7	21.1	9.32	0.2695
Réfrigérateur	0.0	2.6	7.9	3.4	0.2081
Statut de logement					0.2476
Locataire	95.1	94.9	71.1	87.3	
Propriétaire de maison	4.9	5.1	29.0	12.7	
Nombre de chambres					0.3301
1	92.7	79.5	50.0	74.6	
2	4.9	15.4	26.3	15.3	
3 et plus	2.4	5.1	23.7	10.2	
Source d'énergie pour cuisiner					0.3051
1 mange dehors	24.4	7.7	2.6	11.9	
2 bois ou charbon	61.0	33.3	36.8	44.1	
3 gaz	14.6	59.0	60.5	44.1	

La différence la plus nette entre les plus et les moins pauvres est marquée par la possession d'une télévision et l'utilisation du gaz pour cuisiner. Super-positionnés sur la Figure 4.1 on retrouve les trois classes socio-économiques des ménages cultivateurs. La répartition est homogène à travers toutes les zones. La comparaison des problèmes rencontrés par leur nature et ordre d'importance ne relève pas de différences significatives entre les trois classes socio-économiques au niveau des ménages et pas non plus entre les trois strates de « cohésion sociale » au niveau communautaire. Puisque nous n'avons pas obtenu des résultats significatifs, ils ne sont pas discutés dans l'article présent. Les analyses se basent surtout sur nos observations qualitatives dans les zones et les groupes de discussion.

4.6 Discussion

Les capitaux des maraîchers dans le cadre « capital-vulnérabilité »

Figure 4.3 montre les cinq capitaux de l' « asset-vulnerability framework » par Moser (1998) dans le contexte du maraîchage urbain à Abidjan. Les capitaux les plus évidents des pauvres – le travail et les relations au niveau ménage – n'ont pas été discutés.

Le terrain urbain comme capital de subsistance, comparable au capital « housing »

Nous considérons le « terrain urbain » comme un capital productif, générant des revenus, comparable au capital « housing », mis en valeur par des entreprises à domicile (p. ex. coiffure et boutiques). L'utilisation du terrain des berges lagunaires, qui avaient été débroussaillées par les premiers immigrés et occupées progressivement, présente de nombreux avantages (p. ex. sécurité alimentaire, source de revenu, revalorisation de l'entourage physique par les espaces verts). Cependant, le jardinage n'est pas reconnu comme « utilisation du terrain » par l'état. Conformément à la loi, la terre appartient à celui qui la met en valeur, à condition que les droits d'exploitation soient enregistrés formellement (décret du 20 mars 1967, relatif à l'utilisation du territoire; (Heath 1993). L'absence de titres légaux pour les terrains représente une vulnérabilité accrue des maraîchers, déjà marginalisés, car leur sort dépend de la politique du sol. Nous avons observé la destruction des habitations individuelles par l'état sur le terrain de l'Agence de Télécoms de Côte d'Ivoire (ATCI) en novembre 2004 dans les zones 4 et 5. Les décombres avaient été débarrassées et lors de notre passage suivant en février 2005, les jardins étaient à nouveau rétablis comme avant l'intervention. D'après le délégué de ces zones, la concession de l'ATCI envers l'utilisation du territoire actuelle tolère le maraîchage dans ce lieu pour l'instant. Les 30 derniers années, les maraîchers avaient reculé devant la construction des habitations individuelles, un phénomène observé dans toutes les zones où nous avons travaillé.

Capital	Exemples (Moser)	Exemples dans le contexte maraîcher à Abidjan	Niveau d'intervention
Travail & Relations Au niveau ménage	Ressources de travail additionnelles par les membres de famille	Appui de travail dans le jardin par les enfants pendant les congés d'école et les femmes	Ménage
	Genre (division du travail, cotisation des revenus et d'autres ressources)	La femme vend les produits maraîchers du jardin de son mari au marché	
Capital productif (housing)	Propriétaires d'une maison: la diversification des revenus par des entreprises à domicile (p.ex. salon de coiffure au RDC)	Exploitation et valorisation des terrains urbains. Le terrain urbain est comparable au « housing », considéré comme capital productif et capital de subsistance.	Ménage
Capital humain	Accès aux services sociaux (p.ex. éducation) et infrastructures socio-économiques (p.ex. eau, transport, électricité)	Envoi de la femme et des enfants au Burkina Faso (réduction des frais d'école et des frais de vie en général ; assurer l'éducation des enfants)	Ménage Individu
	Substitution des biens privés pour des biens publiques (p.ex. assistance médicale)	Substitution des structures de soins publiques par des services privés et traditionnels (auto-traitement, traitement à l'indigénat, « pharmacie par terre », guérisseurs)	
Capital social	Organisations basés sur la communauté, activités dans la communauté	Communautés maraîchères informelles structurées. Délégués: nœuds d'interconnexion et d'institutionnalisation à l'intérieur, représentants d'intérêts à l'extérieur de la communauté. Activités communautaires (réunions régulières).	Communauté
	Réseau social : arrangements informels de crédits, augmentation des supports informels parmi les ménages selon les capacités	Réseau social entre les maraîchers : travaux de groupe, soutenance d'un collègue en cas de maladie (travaux au jardin, crédits informels), gardes de nuit alternés à cause des vols	

Figure 4.3 Les cinq capitaux de l' « asset-vulnerability framework » de Moser (1998) dans le contexte du maraîchage urbain à Abidjan. Exemples de stratégies de mobilisation des capitaux.

Le capital humain comme capital des maraîchers urbains et des stratégies de préservation

Le développement du capital humain est étroitement lié à la disposition d'infrastructure économique et sociale. Les pauvres urbains ont tendance à substituer les infrastructures sanitaires publiques par des biens et services privés et traditionnelles. Cette substitution stratégique permet de diminuer les dépenses de santé qui, du reste, influencent leur capacité de mobiliser leur travail comme capital (Moser 1998). Face aux difficultés d'accès aux soins de santé publiques, les maraîchers urbains pratiquent l'automédication et les méthodes de soins curatifs à faible coût tels que la pharmacopée et la « pharmacie par terre ». Les ressources économisées sont utilisées autrement, p. ex. pour payer des intrants agricoles (engrais, semences et produits phytosanitaires).

Les cultivateurs sont conscients du fait qu'ils s'exposent à des risques sanitaires en travaillant dans un environnement physique dégradé dû aux dépôts d'ordures, l'immersion permanente dans l'eau, et l'utilisation des produits phytosanitaires. Cette notion de risque se manifeste dans les stratégies de prévention comme p. ex. la maintenance de la propreté de l'entourage du site (parcelles et puits d'arrosage), et par l'abstinence de la consommation de l'eau des puits. Ces stratégies préventives visent à réduire leur vulnérabilité face à des risques des maladies, et de préserver leur instrument et capital de travail, la force physique.

Le « capital social » des communautés maraîchères

La faible variabilité des problèmes principaux est expliquée au niveau du ménage par l'homogénéité du profil et du statut socio-économique. Au niveau communautaire des trois strates de cohésion sociale, nous nous attendions – contrairement à nos résultats – à une association significative entre la nature des problèmes et les trois strates de cohésion, influencés par les agents agricoles (formation aux niveaux de la commercialisation et prévention en face des risques phytosanitaires). Comparant le degré de cohésion, des différences auraient été attendues dans la perception de la sécurité présumant que les délégués sur place renforcent la justification des activités maraîchères par rapport à d'autres zones de faible cohésion. Néanmoins, en vertu de nos analyses qualitatives d'observation, nous attribuons une fonction cruciale aux délégués et aux agents locaux des structures agricoles. Ces résultats montrent en même temps l'importance de la transdisciplinarité méthodologique dans ce genre d'études (la combinaison des méthodes quantitatives et qualitatives).

Les délégués figurent comme nœud d'interconnexion à l'intérieur comme à l'extérieur des communautés maraîchères (Figure 4.4). A l'intérieur, leur présence structure et institutionnalise les communautés maraîchères à travers des réunions qui servent à la diffusion des « nouvelles », et à identifier et les problèmes communs sur les sites de travail. Ils interviennent en outre comme intermédiaires dans les cas de conflits entre les maraîchers. Vers l'extérieur, les délégués figurent comme partenaires de négociation avec les groupes d'intérêts externes. Leur responsabilité est de représenter et négocier les intérêts des maraîchers face aux forces de l'ordre, structures municipales, et aux propriétaires terriens publiques et privés, comme par exemple dans la négociation des services améliorés par la municipalité. Une expérience sur un site démontre cette inter-communication : lors d'un rendez-vous avec un délégué, celui-ci a été empêché de nous recevoir à l'heure arrangée à cause d'une réunion au poste de police municipale dans le cadre d'un recensement des maraîchers dans la zone. Il était chargé de collecter les pièces d'identité de tous les jardiniers sur place et les remettre à la police. Une responsabilité cruciale est attribuée également aux agents des structures agricoles locales sur place pour les consultations professionnelles.

A travers de nos observations discutées ci-dessus, nous considérons le fonctionnement des communautés maraîchères comme une sorte de « capital social » ; un réseau social basé sur l'organisation communautaire informelle des maraîchers de la zone. Le développement du capital social comme capital des maraîchers se traduit aussi et surtout par l'augmentation de la confiance entre eux, par exemple dans les dispositions de crédits informels. Le manque de moyens financiers par la faiblesse des revenus dans le secteur amène les cultivateurs à s'endetter auprès de la communauté pour assurer les frais des médicaments en cas de maladie. Le réseau social peut indiquer la cohésion sociale en terme d'activité communautaire, le travail de groupe. Nous avons observé des cultivateurs qui se regroupent pour planter des alevins butte par butte. Un autre exemple est l'organisation des gardes alternées la nuit face aux vols des potagers. En cas de maladie sérieuse d'un maraîcher, les travaux champêtres de celui-ci sont effectués par la communauté. Les revenus issus de ce travail en groupe lui sont régulièrement versés afin de subvenir aux besoins de ménage. La gestion du capital social influence la résilience des maraîchers urbains. Les communautés maraîchères peuvent contribuer à résilier des situations de vulnérabilité passagère. Toutefois, les résultats de l'étude de Moser (1998) montrent que la permanence du capital social dépend surtout des capitaux des ménages. En d'autres termes, les ménages cultivateurs des sites étudiés peuvent en supporter d'autres seulement s'ils sont en mesure eux-même de le faire.

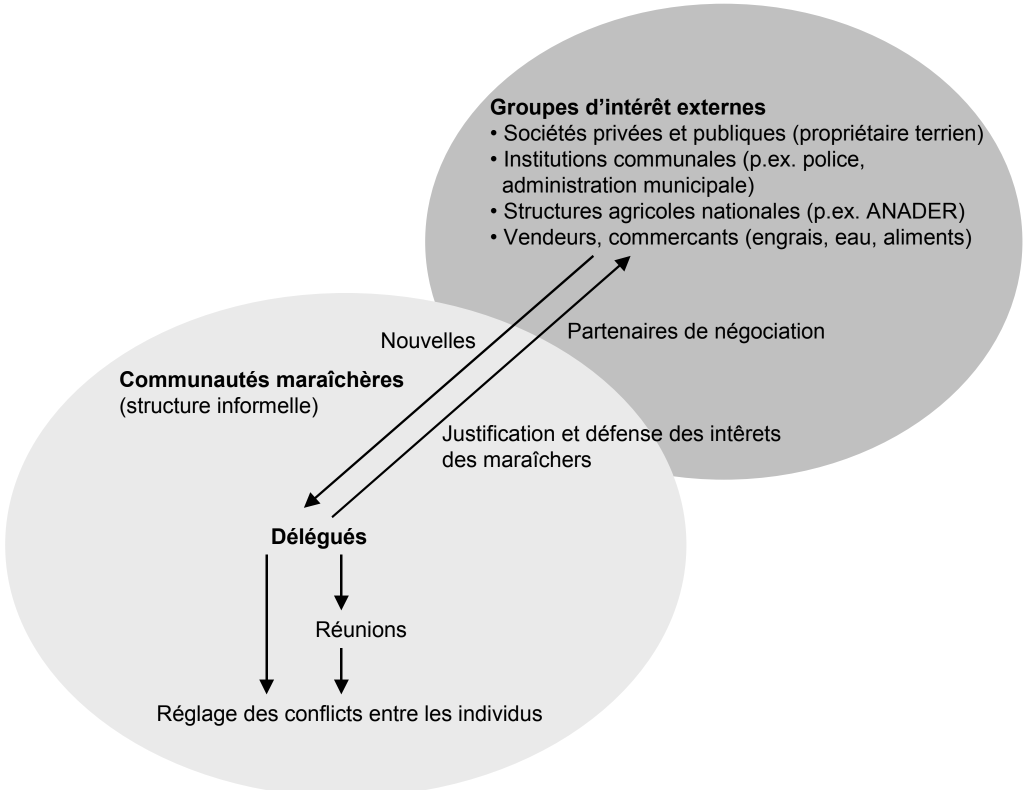


Figure 4.4 Le réseau social dans les communautés maraîchères à Abidjan et le rôle des délégués

4.7 Conclusion

Au terme de notre étude, il résulte que les problèmes de santé sont d'abord refoulés par d'autres préoccupations de subsistance quotidienne et ne réapparaissent qu'en cas d'urgence. Des discussions focalisées sur les représentations des risques sanitaires dans les zones maraîchères d'Abidjan indiquent cependant la conscience des risques sanitaires potentiels : les dépôts d'ordures ménagères sont perçues comme risque sanitaire principale sur le site. Il n'est pourtant pas accordé une attention particulière à la prévention.

Nous avons identifié des capitaux et stratégies spécifiques des maraîchers : le terrain urbain comme capital productif et de subsistance, des stratégies de substitution des infrastructures sanitaires publiques par des privés, et l'automédication. La cohésion sociale dans les communautés maraîchères observées est renforcée par les délégués et les agents des structures agricoles. Elle se manifeste aussi par la confiance entre les maraîchers en cas de crédit, de travaux en groupe et des soutiens en cas de maladie. Elle est pourtant assez fragile, entre autre à cause de la dynamique de l'utilisation du territoire par la politique du marché foncier.

Nos recommandations formulées ci-joint s'intégrant aux objectifs du Millénaire pour le développement, surtout le but 1 « Réduction de l'extrême pauvreté et de la faim », le but 6 « Combattre le VIH/SIDA, le paludisme et d'autres maladies », et le but 7 « Assurer un environnement durable » (WHO & UNICEF 2005) :

- L'encouragement des démarches visant à la reconnaissance par la municipalité de la ville d'Abidjan de l'agriculture urbaine à Abidjan comme « utilisation du terroir », en vue d'améliorer sensiblement la vie des maraîchers et de consolidation leur subsistance (UN-HABITAT 2003) ;

- Le renforcement professionnel et technique des structures informelles des communautés maraîchères à travers la collaboration entre les institutions agricoles, les structures municipales et les délégués ;

- La prévention face aux risques sanitaires liés au maraîchage (Cissé 1997; Daou 1990) à travers la sensibilisation des délégués et maraîchers ;

- L'approvisionnement des structures agricoles sur place des produits agricoles et du matériel protégeant (bottes et gants); et l'aménagement technique en vue d'introduire non seulement des techniques d'irrigation mécanisée pour diminuer les surfaces d'eau (Kruse 1990; SOGREAH 1974), mais surtout aussi des facilitations sanitaires (latrines) pour éviter la contamination des maladies par les excréments humains et la gestion des dépôts ménagères (Cissé 1997).

- La protection sociale à travers la mise en place de mutuelles de santé (micro-assurance maladie) en vue d'éviter une exclusion sociale (BIT 2000; Silem 1994)

Là où les conditions macro-économiques pour la création d'emplois additionnels sont limitées, la reconnaissance de l'utilisation agricole du terrain et le renforcement structurel des communautaires maraîchères sont des mesures importantes de mitigation de la vulnérabilité économique. Malgré les avantages de l'agriculture urbaine, le dialogue politique sur ces propositions s'avère comme difficile. Des études sur la question du développement de l'agriculture urbaine à Abidjan avaient été effectuées avant le déclenchement de la crise socio-économique en septembre 2002 (AGRISUD 1999; BNETD 2001; 2002). L'approche du renforcement structurel est uniquement durable avec l'échange entre les groupes d'intérêt (communautés maraîchères, administrations municipales, structures agricoles) et surtout l'intérêt politique de l'état (Obrist et al. 2006). En plus la dispersion spatiale des zones maraîchères pourrait compliquer l'implantation des programmes spécifiques (Cissé 1997). Il est reconnu que la collaboration horizontale basée sur les institutions communautaires encourage les « réserves » du capital social (Putnam 1993), et que le capital social influence le développement du « capital humain » (Coleman 1990). Dans cette ligne de réflexion, le renforcement des « communautés maraîchères » améliore à long terme les conditions de base de la subsistance des maraîchers.

4.8 Remerciements

Cette étude a été effectuée dans le cadre du programme "Pôle de recherche national (NCCR) Nord-Sud: Partenariats de recherché pour atténuer les syndromes du changement global", Projet Individuel #4 (IP4) intitulé "Renforcer la santé pour créer du bien-être" et du projet "Förderungsprofessur" J. Utzinger, Project No. PPOOB—102883, bénéficiant d'un financement du Fonds National Suisse (FNS). Nos remerciements sont adressés aux personnes suivantes pour leur appui, leurs idées et contributions à cet article : Prof. E.K. N'Goran de l'Université d'Abidjan Cocody, et à Mr. Kone M., Mr. S. Boza, Mr. H. Comoé, Mr. E. Gbede Becket, Mr. C. Brou Kouakou, Mr. F. Dakouri Gbaka, Mr. D. Fofana, et Mme N. Kone ; assistants de terrain à Abidjan. Mais surtout nous voudrons exprimer nos reconnaissances sincères à la participation et collaboration franche des maraîchers à cette étude.

4.9 Références

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5. Urban agricultural land use and characterization of mosquito larval habitats in a medium-sized town of Côte d'Ivoire

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This article has been published in:
Journal of Vector Ecology (2006), **31** (2): 319-333

5.1 Abstract

Urban agriculture is common across Africa and contributes to the livelihoods of urban dwellers. Some crop systems create suitable mosquito breeding sites, and thus might affect malaria transmission. The purpose of this study was to identify, map and characterize potential mosquito breeding sites in agricultural land use zones in a medium-sized town of western Côte d'Ivoire and to assess risk factors for productive *Anopheles* breeding sites. Two surveys were carried out; one toward the end of the rainy season and the second one during the dry season. In all identified potential mosquito breeding sites, two experienced entomologists searched for the presence of *Anopheles* larvae and pupae with a standardised technique. A total of 369 and 589 sites were found in the rainy and dry season, respectively, mainly in vegetable gardens and irrigated rice fields. *Anopheles* larvae were present in 50.7% and 42.4% of the sites investigated during the rainy and dry seasons, respectively. Typical *Anopheles* larval habitats were characterized by the presence of algae, the absence of floating vegetation and the co-occurrence of *Culex* larvae. The highest *Anopheles* larval productivity was observed in rice paddies, agricultural trenches between vegetable patches and irrigation wells. An indirect link could be established between the occurrence of productive *Anopheles* breeding sites and agricultural land use through specific man-made habitats, in particular agricultural trenches, irrigation wells and rice paddies. Our findings have important bearings for the epidemiology and control of urban malaria in sub-Saharan Africa.

Keywords

Malaria, urban agriculture, breeding sites, *Anopheles*, *Culex*.

5.2 Introduction

Malaria causes social and economic hardship and impedes progress toward achieving several of the Millennium Development Goals, particularly in sub-Saharan Africa (Keiser *et al.* 2005; Sachs & Malaney 2002; Snow *et al.* 2005). Due to rapid urbanization, malaria in urban settings is a growing, albeit overlooked problem, and requires more pointed emphasis (Donnelly *et al.* 2005; Hay *et al.* 2005; Keiser *et al.* 2004; Robert *et al.* 2003; Wang *et al.* 2005). Urbanization often results in profound demographic, ecological and socio-economic changes, that are characterized by a high degree of spatial and temporal heterogeneity (Utzinger and Keiser 2006). The adaptation of malaria vectors to urban ecosystems has been documented and warrants close attention (Chinery 1984; Klinkenberg et al. 2005). Importantly, a high proportion of the urban population at any age is at risk of malaria due to lack of acquired immunity (Castro et al. 2004). Since malaria transmission in urban settings is usually lower and more focal than in rural settings (Staedke et al. 2003), urban areas hold promise for vector control and integrated vector management (WHO 2004). Most of the previous research pertaining to urban malaria in sub-Saharan Africa has focused on large cities, including Brazzaville, Congo (Trape & Zoulani 1987), Dar es Salaam, Tanzania (Castro et al. 2004), and Abidjan, Côte d'Ivoire (Wang et al. 2006).

In view of the rapidly growing number of small- and medium-sized towns, there is a pressing need to improve our understanding of the epidemiology of malaria in these settings. As the human population density is usually lower in smaller towns, a higher fraction of open space is available for agriculture, which in turn may create productive mosquito breeding sites and might affect malaria transmission.

Urban agriculture encompasses the production, processing and distribution of food, comprising vegetable and animal products in intra- and peri-urban areas (Baumgartner & Belevi 2001). In African countries, urban agriculture plays an important role for food security and improving local livelihoods. On the other hand, irrigated urban agriculture might affect malaria transmission intensity and dynamics through the creation of suitable breeding sites, as has been documented recently in urban settings of Ghana (Afrane et al. 2004; Klinkenberg et al. 2005).

The purpose of the current study was to investigate factors that govern the presence of *Anopheles* larvae in urban agricultural zones, and to derive typical features of particularly productive larval habitats, by means of a standardized sampling approach. This included the identification, mapping and characterization of potential mosquito breeding sites in seven selected zones of irrigated agricultural land use, in both the rainy and dry seasons, in a medium-sized town of Côte d'Ivoire.

5.3 Materials and methods

Study area

The study was carried out between September 2004 and March 2005 in the town of Man, western Côte d'Ivoire. This area has a climate of tropical rainforest with two distinct seasons; the rainy season occurs between April and October, with peak rainfall in June/July, and the dry season is between November and March (Utzinger et al. 2000). The annual precipitation between September 2001 and August 2002 was 838-1259 mm in nearby villages according to remotely-sensed satellite data (Raso et al. 2006). The town of Man lies at an altitude of 320 m above sea level, and is surrounded by mountains with altitudes up to 1300 m (Raso *et al.*

2006; Utzinger *et al.* 2000). Water drawn from the Kô River, crossing the town from northwest to southeast, is used for irrigating agricultural plots that are primarily located in the southwestern part of the town. According to the 1998 census, the estimated population of Man was 115,000.

We identified seven agricultural zones that comprise irrigated crop systems (Figure 5.1). Zones 1-4 and 6 are located in the town of Man, while the remaining zones 5 and 7 are on its outskirts. Zones 1 and 3 contain mixed crop areas, i.e. traditional smallholder irrigated rice cultivation in the lowland and vegetable gardens along the borders of the rice paddies and riverbanks. Zone 2 consists of vegetable gardens and a few individual rice plots, mainly located at the riverside. Rice is the predominant crop in zones 4-7; whereas zones 4 and 6 consist of traditional smallholder irrigated rice areas, zones 5 and 7 are large rice-perimeters at the periphery that were established in the 1990s. In zone 7, traditional inland valley rice plots are also found.

Characterization of potential mosquito breeding sites

Two 12-day surveys were carried out for the identification, geo-referencing and characterization of potential mosquito breeding sites in the selected agricultural zones. The first survey was conducted toward the end of the rainy season (September 2004) and the second one at the end of the dry season (March 2005). Each identified open water body within the respective agricultural zones was considered as a potential breeding site, except for rice perimeters, where only every second rice plot was investigated. First, the selected open water bodies were geo-referenced, using two hand-held global positioning system (GPS) receivers (eTrex and Garmin 12XL, Garmin International Inc.; Olathe, USA). Next, the potential breeding sites were examined in a standardized way. We used an appraisal form previously employed in Dar es Salaam (Sattler et al. 2005) after pre-testing and further adaptation to our setting. Environmental characteristics in close proximity to the breeding sites were described, including crop and habitat types. The following physical variables were investigated for each site: perimeter, water movement, turbidity, sunlight and presence of solid waste. Vegetation and presence of potential predators were considered as key biological variables. The phenological development stage of rice plants was estimated and grouped into five categories: (i) flooded plots and recently transplanted rice seedlings, (ii) tillering plants, (iii) panicle differentiation until polinisation, (iv) heading (panicle extruding) and maturation, and (v) idle plots, referring to (Moldenhauer & Slaton 2004).

Dipping techniques were performed according to a recent *Anopheles* breeding site assessment conducted in Dar es Salaam (Sattler et al. 2005). Ten dips were performed in each site, using a standard 350 ml dipper. The presence of *Anopheles* larvae was defined by at least one larva found in any of the 10 dips. The density of *Anopheles* and *Culex* larvae was stratified into three classes: (i) high: presence of larvae in at least seven dips, (ii) moderate: presence of larvae in four to six dips, and (iii) low: presence of larvae in one to three dips. The same sampling method and density definitions were used for pupae of *Anopheles* plus *Culex*, and potential predators, such as water insects (e.g. dragonfly (genus *Anisoptera*), backswimmers (family *Notonectidae*)) and tadpoles. We also recorded the presence of fish and aquatic snails usually by direct observation, but in some cases following discussion with farmers on the spot.

Interviews with farmers

In the selected agricultural zones, we identified a total of 171 households primarily engaged in urban agriculture. In October 2004, the heads of these households were interviewed on common practices in agriculture and water use. Eight months later, household members were invited to participate in a cross-sectional epidemiological survey, as described elsewhere (Matthys *et al.* 2006).

Data management and statistical analysis

All data were double entered and cross-checked using version 3.1 of the EpiData software (EpiData Association; Odense, Denmark). Statistical analyses were done in version 9.0 of the STATA software package (Stata Corporation; College Station, USA). Maps were created in version 9.0 ESRI ArcMap (Redlands, USA).

The frequencies of larvae and pupae observed in different habitat types were compared by using χ^2 test or Fisher's exact test, as appropriate. Spearman's non-parametric rank correlation was applied to test for the correlation between the number of *Anopheles* larvae and pupae of *Anopheles* and *Culex* by habitat and season. Bivariate and multivariate logistic regression models were fitted to identify parameters that determined the presence and density of larvae and pupae. A stepwise backward elimination approach was applied, and covariates above a level of 0.2 were removed from the model one after another. We tested for the interactions between season and other covariates and incorporated significant interaction terms in the model. For analysis of larval density, moderate and high density classes were merged and grouped as "high density". In order to identify key factors affecting the larval density, we used a generalized logistic regression model (Williams 2005) and included only data derived from sites where *Anopheles* larvae were present. The different rice growth stages were excluded from the multivariate models because they were not assessed systematically. Likelihood ratio test (LRT) statistics were employed to test for significant relations between the investigated variables and the outcome. For all tests, 95% confidence intervals (CIs) were calculated.

5.4 Results

Crops cultivated in the town of Man

The study area, specifically the agricultural plots and farmers' houses in the seven selected agricultural zones, is depicted in Figure 5.1. Interviews with the heads of household engaged in urban agriculture revealed that the majority of cultivated crops were rice- and vegetable-based; 64.9% of all households cultivated rice and 42.7% had vegetable gardens. Irrigated rice was cultivated by over 60% of all households, mainly in inland valleys. Rain-fed rice was grown by 16.4% of the farmers on hill flanks in peri-urban areas. Leaf vegetables (mainly lettuce and peppermint), fruit vegetables (e.g. eggplants and okra) and tuber and root vegetables (e.g. carrots and onion) were cultivated by 36.5%, 7.0% and 5.9%, respectively. A few farmers also cultivated rain-fed crops, mainly manioc, banana and to a lesser extent maize. Fish farming was reported by 8% of the households.

Physical and biological characteristics of potential mosquito breeding sites

Table 5-1 summarizes physical and biological characteristics of the identified potential mosquito breeding sites. Overall, 958 sites were examined; 369 (38.5%) toward the end of the rainy season and 589 (61.5%) in the dry season. Investigated sites were mainly rice paddies (44.3%), irrigation wells (28.8%), natural ponds, pools and fish ponds (9.3%) and agricultural trenches (8.5%). The large majority of the sites contained stagnant water, and two-thirds of the sites had transparent water.

Aquatic vegetation was observed in 89.0% of the sites investigated; herbs/grass in 65.1%, algae in 26.2%, and floating vegetation, e.g. liverwort (*Ricciocarpus natans*) and common duckweed (*Limna minor*), in 14.0%. Potential predators, mainly water insects, were found in 53.9% of the sites.

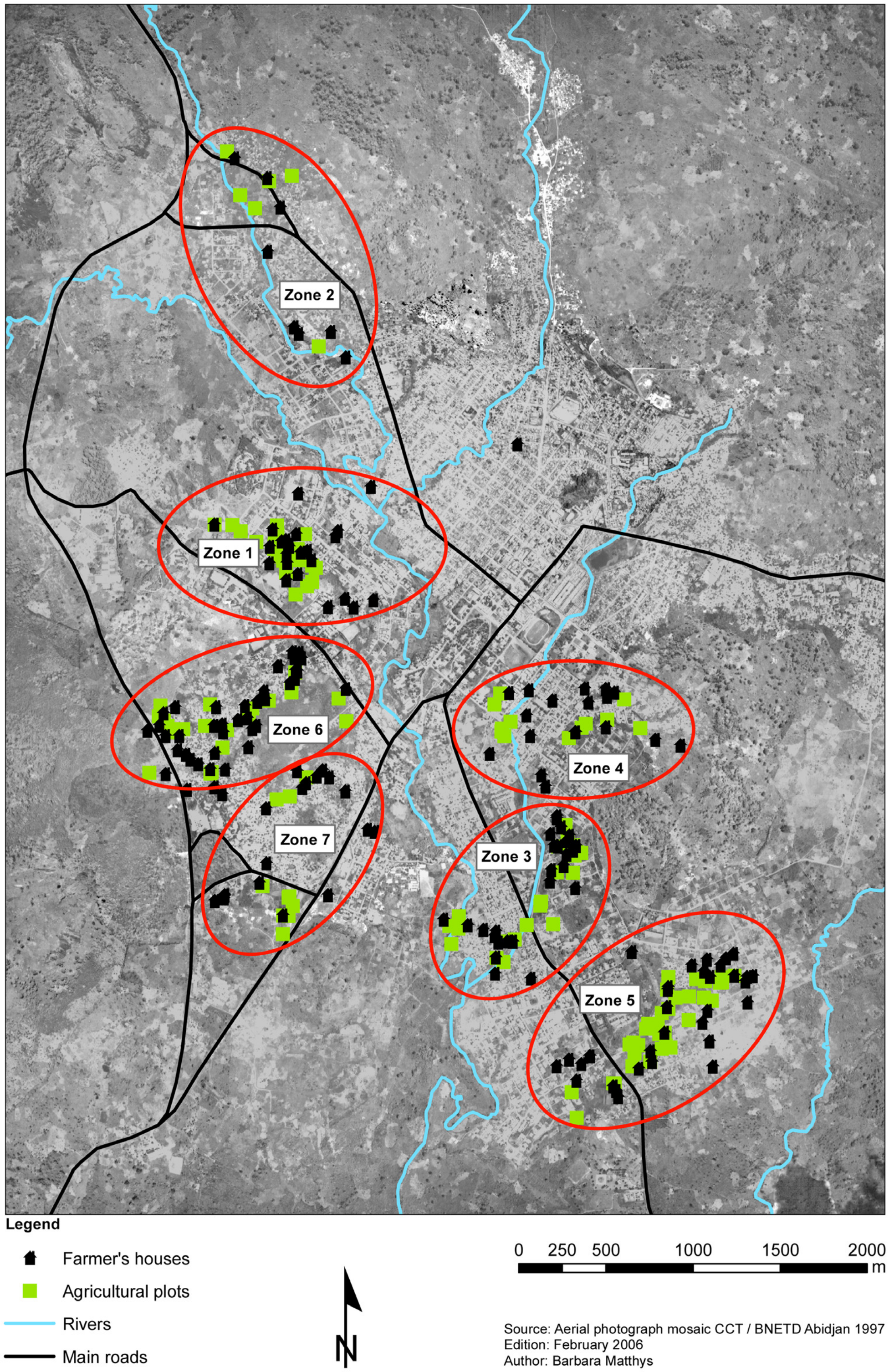

Figure 5.1 Study area and seven selected agricultural zones in the town of Man, western Côte d'Ivoire

Table 5-1 Number (%) of habitat characteristics of potential mosquito breeding sites in the town of Man, western Côte d'Ivoire (n = 958)

Habitat characteristics	Number (%)
Season	
Rainy (September 2004)	369 (38.5)
Dry (March 2005)	589 (61.5)
Habitat type	
Rice paddy	421 (44.3)
Irrigation well	274 (28.8)
Natural pond or pool	46 (4.8)
Fish pond	42 (4.4)
Agricultural trench[a]	81 (8.5)
Riverbank of Kô River	61 (6.4)
Creek, source	20 (2.1)
Irrigation canal, drain	6 (0.6)
Not known	7 (0.7)
Physical characteristics	
Perimeter	
<1 m	112 (11.7)
1-10 m	376 (39.3)
>10 m	448 (46.8)
Not known	22 (2.3)
Water movement	
Stagnant	901 (94.1)
Flowing	47 (4.9)
Not known	10 (1.1)
Turbidity	
Transparent	638 (66.6)
Turbid[b]	275 (28.7)
Very turbid[c]	17 (1.8)
Not known	28 (2.9)
Presence of solid waste	228 (23.8)
Not known	23 (2.4)
Sunlight	
Shade: 1-25%	566 (59.1)
Shade: >25%	390 (40.7)
Not known	2 (0.2)
Biological characteristics	
Aquatic vegetation	853 (89.0)
Herbs/grass	624 (65.1)
Algae	251 (26.2)
Floating vegetation	134 (14.0)
Not known	23 (2.4)
Potential predators	
All predators	516 (53.9)
Water insects	424 (44.3)
Tadpoles	124 (12.9)
Fish	110 (11.5)
Not known	42 (4.4)

[a]Agricultural trench, fosse and puddle between vegetable patches; [b] Bottom of dipper still visible; [c] Bottom of dipper not visible

Presence and density of *Anopheles* and *Culex* larvae and pupae

Figure 5.2 shows the spatial distribution of the potential breeding sites examined toward the end of the dry season. *Anopheles* larvae were found in sites marked with red colour (moderate and high density) and yellow colour (low density), while they were absent in sites marked in green colour. The presence of pupae (both *Anopheles* and *Culex*) in the dry season was restricted to those sites marked with an asterisk. Although larvae were not systematically hatched for species identification, a few selected specimens hatched in March 2005, which belonged to *Anopheles funestus* and the *An. gambiae* complex. Both species are important malaria vectors and were commonly reported in the forest and wet savannah zones of Côte d'Ivoire in recent studies (Betsi et al. 2003; Briët et al. 2003; Koudou et al. 2005).

Table 5-2 summarizes the number and percentage of sites where *Anopheles* and *Culex* larvae and pupae were found in different habitat types during the two surveys. *Anopheles* larvae were identified in 50.7% and in 42.4% of all sites examined toward the end of the rainy and dry season, respectively. The respective percentages of *Culex* larvae were 20.9% and 30.4%, and those of pupae of *Anopheles* plus *Culex* were 6.2% and 13.8%. Rice paddies, agricultural trenches and irrigation wells were the preferred *Anopheles* larval habitats in both seasons. The highest frequencies of habitat types inhabited by *Culex* larvae toward the end of the rainy season were observed in natural ponds/pools and irrigation canals, whereas in the dry season preferred habitat types were rice paddies. Pupae of *Anopheles* and *Culex* preferred agricultural trenches in both seasons.

The presence of *Anopheles* larvae in the seven agricultural zones varied between 33.3% (zone 6) and 70.8% (zone 1) in the rainy season, and between 19.8% (zone 2) and 59.3% (zone 3) in the dry season. The occurrence of pupae varied between 4.1% (zone 5) and 11.1% (zone 4) in the rainy season and between 2.2% (zone 1) and 22.4% (zone 5) in the dry season. In both seasons, high frequencies of *Anopheles* were observed in zones 5 and 7, representing large rice perimeters. In the vegetable production sites (zone 2), larval prevalence was lower in the dry season. In areas of mixed vegetable-rice cultivation (zones 1 and 4), there was a large temporal variation of the frequency of *Anopheles* larvae.

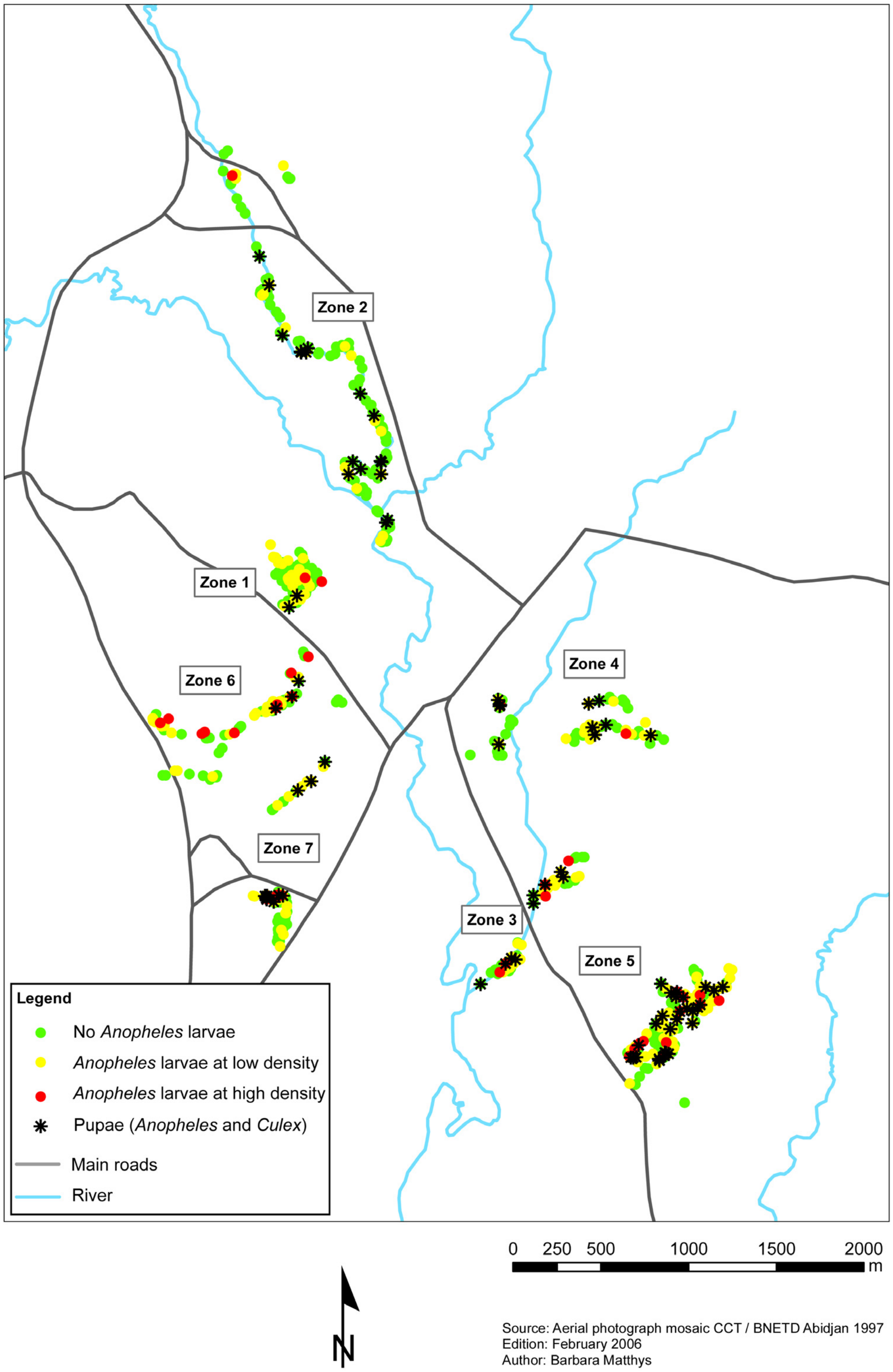

Figure 5.2 Spatial distribution of potential breeding sites in the town of Man, western Côte d'Ivoire, including status of *Anopheles* larvae and pupae (*Anopheles* plus *Culex*) in the dry season survey in March 2005

Table 5-2 Number (%) of sites where larvae and pupae of *Anopheles* and *Culex* were found toward the end of the rainy season and during the dry season in the town of Man, western Côte d'Ivoire

Habitat type	Total sites in rainy season	Total sites in dry season	*Anopheles* larvae		*Culex* larvae		Pupae (*Anopheles* and *Culex*)	
			Positive sites rainy season	Positive sites in dry season	Positive sites in rainy season	Positive sites in dry season	Positive sites in rainy season	Positive sites in dry season
Rice paddy	246	175	143 (58.1)	92 (52.6)	52 (21.1)	67 (38.3)	17 (6.9)	23 (13.1)
Agricultural trench	38	43	17 (44.7)	29 (67.4)	9 (23.7)	15 (34.9)	4 (10.5)	11 (25.6)
Irrigation well	27	247	12 (44.4)	100 (40.5)	6 (22.2)	68 (27.5)	1 (3.7)	31 (12.6)
Natural pond or pool	23	23	6 (26.1)	9 (39.1)	6 (26.1)	8 (34.8)	1 (4.3)	4 (17.4)
Fish pond	16	26	2 (12.5)	9 (34.6)	2 (12.5)	3 (11.5)	0 (0)	1 (3.8)
Riverbank of Kô River	4	57	2 (50.0)	7 (12.3)	0 (0)	12 (21.1)	0 (0)	8 (14.0)
Creek, source	12	8	4 (33.3)	2 (25.0)	1 (8.3)	3 (37.5)	0 (0)	1 (12.5)
Irrigation canal, drain	3	3	1 (33.3)	0 (0)	1 (33.3)	1 (33.3)	0 (0)	0 (0)
Not known	0	7	0 (0)	2 (28.6)	0 (0)	2 (28.6)	0 (0)	2 (28.6)
Total	369	589	187 (50.7)	250 (42.4)	77 (20.9)	179 (30.4)	23 (6.2)	81 (13.8)

Environmental factors (physical and biological) governing the presence of *Anopheles* larvae and pupae (*Anopheles* and *Culex*)

Table 5-3 shows the results of the bivariate logistic regression models used to identify environmental factors that govern the presence of *Anopheles* larvae and the presence of pupae of *Anopheles* and *Culex*. Rice paddies (odds ratio (OR) = 2.02, 95% CI = 1.56-2.62) and agricultural trenches (OR = 1.60, 95% CI = 1.01-2.53) were preferred habitat types of *Anopheles* larvae. In contrast, river banks of the Kô River (OR = 0.19, 95%, CI = 0.09-0.38) and fish ponds (OR = 0.40, 95% CI = 0.20-0.81) were avoided. Typical features of *Anopheles* larval habitats comprised of stagnant and turbid water, the presence of algae and any kind of predators, particularly water insects.

When all physical and biological characteristics were included in a multivariate model, the habitat types rice paddy (OR = 5.83, 95% CI = 2.88-11.82), agricultural trench (OR = 5.58, 95% CI = 2.43-12.77) and irrigation well (OR = 2.71, 95% CI = 1.32-5.54) were more likely being inhabited by *Anopheles* larvae than the other habitats (Table 5-4). The presence of *Anopheles* larvae in sites with algae was associated with an OR of 2.09 (95% CI = 1.26-3.41).

Table 5-3 also shows that the bivariate model predicted that the odds to find pupae (*Anopheles* and *Culex*) in agricultural trenches was 2.04 (95% CI = 1.12-3.74) compared to other habitat types. Pupae were unlikely to be found in fish ponds (OR = 0.19, 95% CI = 0.03-1.41). Factors at the micro-habitat level governing the occurrence of pupae were the presence of algae (OR = 1.62, 95% CI = 1.05-2.49), and tadpoles (OR = 1.95, 95% CI =1.15-3.30). The multivariate model confirmed that pupae were more likely to occur in sites containing algae (OR = 1.97, 95% CI = 1.20-3.23), whereas other habitat characteristics showed no statistical significance (Table 5-4).

Association between presence of *Anopheles* larvae and development stage of rice plants

The development stages of rice plants were assessed for 258 rice plots and associations with the presence of *Anopheles* larvae are presented in Table 5-5. Compared to flooded and recently transplanted paddies with rice seedlings reaching a vegetation cover (VC) of 10-30%, the odds to find *Anopheles* larvae were considerably lower in plots with further developed rice plants (e.g. concomitant VC over 75%, OR = 0.37, 95% CI = 0.18-0.77). Similarly, the presence of pupae was significantly less likely in rice paddies that were at a more developed stage (OR = 0.34, 95% CI = 0.12-0.97 for VC 10-30%; OR = 0.17, 95% CI = 0.05-0.60 for VC 30-75%, and OR = 0.06, 95% CI = 0.01-0.45 for VC >75%).

Table 5-3 Results of bivariate logistic regression models. Outcome: presence vs. absence of *Anopheles* larvae and pupae (*Anopheles* and *Culex*); explanatory variable: habitat parameters

Habitat characteristics	*Anopheles* larvae			*Anopheles* and *Culex* pupae		
	OR[a]	95% CI	*P*-value[b]	OR[a]	95% CI	*P*-value[b]
Season						<0.001
Rainy (September 2004)	1.00			1.00		
Dry (March 2005)	0.69	(0.53, 0.89)	0.005	2.40	(1.48, 3.89)	
Physical characteristics						
Water movement						
Flowing water	1.00			1.00		
Stagnant water	2.57	(1.32, 5.01)	0.003	1.31	(0.46, 3.73)	0.600
Turbidity						
Clear water	1.00			1.00		
Turbid water	1.43	(1.09, 1.89)	0.011	1.56	(1.02, 2.39)	0.045
Sunlight						
>25% shade	1.00			1.00		
0-25% shade	1.59	(1.23, 2.07)	<0.001	0.89	(0.59, 1.35)	0.588
Dense waste						
Absence	1.00			1.00		
Presence	0.72	(0.53, 0.97)	0.030	1.04	(0.64, 1.68)	0.880
Habitat type						
Other	1.00			1.00		
Creek, source	0.49	(0.19, 1.29)	0.136	0.43	(0.06, 3.27)	0.356
Natural pond or pool	0.57	(0.36, 0.91)	0.016	0.58	(0.25, 1.38)	0.188
Fish pond	0.40	(0.20, 0.81)	0.007	0.19	(0.03, 1.41)	0.033
Irrigation well	0.74	(0.56, 0.98)	0.037	1.15	(0.74, 1.79)	0.549
Agricultural trench	1.60	(1.01, 2.53)	0.045	2.04	(1.12, 3.74)	0.028
Rice paddy	2.02	(1.56, 2.62)	<0.001	0.79	(0.53, 1.19)	0.264
Irrigation canal, drain	0.23	(0.03, 1.99)	0.126			
Riverbank of Kô River	0.19	(0.09, 0.38)	< 0.001	1.28	(0.59, 2.77)	0.545
Vegetation						
Absence	1.00			1.00		
Presence	1.52	(0.95, 2.44)	0.075	1.63	(0.69, 3.83)	0.238
Herbs/grass: presence	0.87	(0.66, 1.14)	0.309	1.24	(0.79, 1.94)	0.340
Floating vegetation: presence	0.88	(0.61, 1.28)	0.514	0.61	(0.31, 1.21)	0.138
Algae: presence	1.65	(1.23, 2.21)	<0.001	1.62	(1.05, 2.49)	0.032
Predators						
Absence	1.00			1.00		
Presence	2.39	(1.82, 3.13)	<0.001	0.95	(0.62, 1.45)	0.815
Tadpoles: presence	1.76	(1.20, 2.58)	0.004	1.95	(1.15, 3.30)	0.018
Water insects: presence	2.51	(1.92, 3.29)	<0.001	0.98	(0.64, 1.50)	0.925
Fish: presence	0.97	(0.65, 1.45)	0.877	0.46	(0.20, 1.08)	0.048
Culex						
Absence	1.00			1.00		
Presence	1.96	(1.46, 2.61)	<0.001	4.79	(3.14, 7.31)	<0.001
Anopheles						
Absence				1.00		
Presence				2.32	(1.52, 3.55)	<0.001

[a] Crude odds ratio (OR); [b] *P*-value based on likelihood ratio test (LRT)

Table 5-4 Results of the multivariate logistic regression models (adjusted by season). Outcomes: a) presence vs. absence of *Anopheles* larvae and b) presence vs. absence of pupae (*Anopheles* and *Culex*); explanatory variable: habitat parameters

Explanatory variables: habitat characteristics	*Anopheles* larvae (n = 814)			*Anpoheles* and *Culex* pupae (n = 774)		
	OR[a]	95% CI	*P*-value[b]	OR	95% CI	*P*-value
Turbidity						
Clear water				1.00		
Turbid water				1.41	(0.85, 2.33)	0.402
Habitat type						
Other	1.00					
Creek, source	2.26	(0.97, 5.25)	0.339			
Irrigation well	2.71	(1.32, 5.54)	0.043	0.61	(0.34, 1.08)	0.402
Agricultural trench	5.58	(2.43, 12.77)	0.001			
Rice paddy	5.83	(2.88, 11.82)	0.003			
Vegetation						
Floating plants: absence	1.00					
Presence	0.68	(0.44, 1.05)	0.079	0.48	(0.20, 1.18)	0.086
Algae: absence	1.00					
Presence	2.09	(1.26, 3.41)	0.009	1.97	(1.20, 3.23)	0.023
Predators						
Tadpoles: absence				1.00		
Presence				2.03	(1.11, 3.73)	0.088
Culex						
Absence	1.00					
Presence	1.53	(0.99, 2.38)	0.057			

Table 5-5 Results of bivariate logistic regression model. Outcome: presence vs. absence of *Anopheles* larvae and pupae (*Anopheles* and *Culex*); explanatory variable: development stage of rice plants. (Number of plots where rice growth stage of rice plants was systematically investigated: n = 258)

Development stage of rice plants	Number (%)	*Anopheles* larvae			Pupae (*Anopheles* and *Culex*)		
		OR[a]	95% CI	*P*-value[b]	OR[a]	95% CI	*P*-value
0-10% (flooded-1st tiller)	78 (30.2)	1.00			1.00		
10-30% (2nd tiller-1st panicles)	48 (18.6)	1.16	(0.54, 2.51)		0.34	(0.12, 0.97)	
30-75% (panicles-polinisation)	53 (21.3)	0.59	(0.29, 1.20)		0.17	(0.05, 0.60)	
>75% (heading-maturity)	51 (19.8)	0.37	(0.18, 0.77)		0.06	(0.01, 0.45)	
>50% (idle plot)	26 (10.1)	0.33	(0.13, 0.83)	<0.001	0.87	(0.31, 2.47)	<0.001

[a]Crude odds ratio (OR), *P*-value based on likelihood ratio test (LRT)

Table 5-6 Results of bivariate and of multivariate logistic regression model. Outcome: density of *Anopheles* larvae (1 = low density, 2 = high density); explanatory variable: habitat characteristics

Habitat characteristics	*Anopheles* density[a]	Bivariate model			Multivariate model (n = 380)		
		OR	95% CI	*P*-value	OR	95% CI	*P*-value
Physical							
Flowing water	high	0.78	(0.17, 3.63)	0.747			
Turbid water	high	1.68	(1.03, 2.72)	0.035			
Sunlight (0-25% shade)	high	1.41	(0.84, 2.35)	0.185			
Habitat type							
Creek, source	high	0.80	(0.09, 6.90)	0.831			
Natural pond or pool	high	1.66	(0.70, 3.90)	0.264			
Irrigation well	high	0.85	(0.49, 1.48)	0.569			
Agricultural trench	high	3.31	(1.74, 6.30)	<0.001	4.28	(2.03, 9.04)	<0.001
Rice paddy	high	0.63	(0.39, 1.02)	0.058			
Fish pond	high	2.35	(0.67, 8.23)	0.201			
Vegetation							
Vegetation: presence	high	0.93	(0.36, 2.35)	0.871			
Herbs/grass: presence	high	0.64	(0.40, 1.05)	0.080	0.58	(0.33, 1.01)	0.057
Floating vegetation: presence	high	0.35	(0.14, 0.90)	--	0.32	(0.11, 0.94)	0.019
Algae: presence	high	2.10	(1.29, 3.44)	0.003	1.96	(1.12, 3.44)	0.020
Development stages of rice plants[b]				0.266			
0-10%		1.00					
10-30%	high	0.51	(0.16, 1.59)				
30-75%	high	0.21	(0.04, 1.01)				
>75%	high	0.67	(0.19, 2.36)				
>50%	high	0.72	(0.13, 3.79)				
Predators							
Predators: presence	high	0.96	(0.57, 1.63)	0.888			
Tadpoles: presence	high	0.80	(0.41, 1.58)	0.519			
Water insects: presence	high	0.92	(0.56, 1.50)	0.729			
Fish: presence	high	1.27	(0.61, 2.61)	0.048	1.18	(0.48, 2.03)	0.716
Culex: density				0.001			0.005
Absence	low	1.00			1.00		
Low density	high	0.77	(0.44, 1.37)		1.06	(0.56, 2.01)	
High density	high	4.58	(1.92, 10.91)		4.55	(1.79, 11.56)	
Snails: presence	high	1.20	(0.54, 2.64)	0.648			

[a]*Anopheles* density: low = baseline; [b]Development stages of rice plants are not included in multivariate analysis

Environmental factors determining the density of *Anopheles* and *Culex*

Habitat characteristics affecting the density of Anopheles larvae are shown in Table 5-6. High densities of *Anopheles* larvae were primarily observed in agricultural trenches (OR = 3.31, 95% CI = 1.74-6.30). Habitats with turbid water (OR = 1.68, 95% CI = 1.03-2.72), presence of algae (OR = 2.10, 95% CI = 1.29-3.44) and particularly those co-inhabited by *Culex* larvae at high density (OR = 4.58, 95% CI = 1.92-10.91) showed higher *Anopheles* densities than the other habitat types. The presence of floating vegetation was negatively associated with *Anopheles* larval density (OR = 0.35, 95% CI = 0.14-0.90).

In the multivariate model, agricultural trenches (OR = 4.28, 95% CI = 2.03-9.04), the presence of algae (OR = 1.96, 95% CI = 1.12-3.44) and the co-occurrence of *Culex* larvae at high density (OR = 4.55, 95% CI = 1.79-11.56) were associated with high densities of *Anopheles* larvae. The co-existence of *Anopheles* and *Culex* larvae showed a positive association, particularly in rice paddies ($\rho = 0.207$, $P = 0.006$) and irrigation wells ($\rho = 0.249$, $P < 0.001$) during the dry season.

5.5 Discussion

Three findings emerge from our study, which contribute to further our understanding of the ecology of mosquito larvae and the epidemiology of malaria in typical agricultural zones in the town of Man, western Côte d'Ivoire. It is conceivable that these findings are also important for other medium-sized towns in malaria-endemic settings of the humid tropics. First, we employed a standardized approach for identification, geo-referencing and characterization of potential *Anopheles* breeding sites. This approach had recently been used in a mega city of East Africa (Sattler et al. 2005) within the frame of a broader rapid urban malaria appraisal (RUMA) tested across Africa (Wang et al. 2005), and was readily adapted for our study setting. In two 12-day surveys, one each carried out toward the rainy and dry season, our team of 2-3 investigators managed to identify and characterize a total of 958 potential breeding sites in the 7 selected agricultural zones. Second, in more than half of the sites investigated during the rainy season, we observed *Anopheles* larvae (50.7%), whereas 42.4% of the sites investigated in the dry season were inhabited by *Anopheles* larvae. Third, irrigated rice paddies, as well as agricultural trenches and irrigation wells in vegetable gardens, were particularly productive larval habitats. The occurrence of *Anopheles* larvae and pupae of *Anopheles* and *Culex* was particularly pronounced in flooded and recently planted rice paddies, but decreased significantly as rice plants grew. The most highly populated habitats were agricultural trenches.

Four limitations are worth highlighting with regard to our appraisal of potential *Anopheles* and *Culex* breeding sites. First, *Anopheles* larvae were not identified at species level. However, recent work carried out in forest and wet savannah zones of Côte d'Ivoire confirmed that *An. gambiae s.l.* and *An. funestus* were the predominant species (Betsi et al. 2003; Briët et al. 2003; Koudou et al. 2005), hence the knowledge gained in the current study will be relevant for spatial targeting of vector control measures. In subsequent studies, it will be important to differentiate breeding site preferences for these two malaria vector species, as they show distinct differences in larval ecology (Gimnig et al. 2001). Second, some species of *Culex* (e.g. *Cx. tigripes*) are predators of *Anopheles* larvae, thus species identification will be necessary also for *Culex* larvae to further improve upon biological characteristics of potential breeding site preferences. Indeed, the presence of *Cx. tigripes* was observed, however at a very low frequency (< 1% of the sites investigated) and always as the single mosquito species. Third, in view of limited financial resources, only two surveys could be carried out, one in each season. Clearly monthly surveys would have facilitated more detailed appraisal of breeding site dynamics and their productivity. Indeed, recent studies carried out in large towns of Africa stress the large spatio-temporal heterogeneity of *Anopheles* larval breeding sites (Sattler et al. 2005, Wang et al. 2005, Killeen et al. 2006, Vanek et al. 2006). Fourth, no precise rainfall data were available for the specific study sites during the investigation, because the local meteorological station had been destroyed during the socio-political unrest that commenced in September 2002 (Betsi et al. 2006). Detailed information on precipitation is important to assess whether prevailing meteorological conditions were similar to previous years or whether they were atypical as recently observed in an East African mega city (Sattler et al. 2005).

Seasonal effects

The somewhat higher frequency of breeding sites inhabited by *Anopheles* in the rainy season compared to the dry season is in accordance to previous investigations made in irrigated rice cultivations in southern Sri Lanka (Premasiri et al. 2005). These observations could be explained by the annual variation of precipitation, since rainfall modifies the insolation and water temperature of water bodies. Rainfall, especially the first rains after the dry season, modifies also the permeability of specific soil types (e.g. saturated clay and alluvial soils often found along river banks), thus favouring the creation of small puddles and potential breeding sites (Bogh et al. 2003; Koenraadt et al. 2004). Agricultural zones 1 and 3, dominated by vegetable gardens, are located along the Kô River, and are regularly flooded after heavy rains.

Recent observations suggest that *An. gambiae* larvae can survive a few days in drying habitats given sufficient humidity of the soil. If larvae survive for a short period in small and rapidly drying water bodies, such as the short-lived agricultural trenches, these kind of habitats could turn out as extremely adaptive malaria vector breeding sites, if minimal rainfall is provided within a few days (Koenraadt et al. 2003). In contrast, irrigation wells, which were permanently supplied with ground water reaching almost the surface level, represented the most important larval habitats during the dry season in our study.

Crop types and related water bodies affecting the larval productivity

Our observations that rice paddies, agricultural trenches and irrigation wells represent highly productive *Anopheles* breeding sites are consistent with recent findings from Kumasi, Ghana (Afrane et al. 2004) and Dar es Salaam (Sattler et al. 2005). *Anopheles* breeding in watering installations within market gardens has also been observed previously (Chinery 1984; Lindsay *et al.* 1990; Trape *et al.* 1992; Trape & Zoulani 1987).

We also found that flooded and recently planted rice paddies provide highly productive *Anopheles* larvae habitats, which is in agreement with previous observations. Although most of the investigations were conducted in rural areas, the highest larval densities had also been observed in plots with young rice plants, and densities decreased significantly with growing plant height (Betsi *et al.* 2003; Boelee 2003; Briët *et al.* 2003; Doannio *et al.* 2002; Dossou-Yovo *et al.* 1998; Klinkenberg *et al.* 2003), or after the application of fertilizers (Mutero et al. 2004). Flooded plots offer large surfaces of shallow and clear water, and thus excellent breeding conditions for *Anopheles* (Service 1996). Idle plots in our study sites often contained drying pools and puddles within vegetation-free spots, they were generally undisturbed by human activity and hence represented highly productive larval and pupal habitats. Nevertheless, rice cultivation *per se* does not necessarily affect malaria incidence rates, as they are also governed by socio-economic and cultural factors (De Plaen *et al.* 2003; Henry *et al.* 2003; Ijumba & Lindsay 2001; Keiser *et al.* 2005), and other agricultural practices (Ijumba et al. 2002a; Ijumba et al. 2002b; Sissoko et al. 2004).

Physical and biological factors

The positive association we found between *Anopheles* larvae and the presence of algae confirms previous observations made in western Kenya (Gimnig et al. 2001) and Mexico (Fernandez-Salas et al. 1994; Gimnig et al. 2001). The presence of algae might indicate the longevity of a water body; the more permanent a habitat is, the more likely is the proliferation of algae, which in turn provide nutrients for mosquito larvae. Conversely, a negative association with algae content, and a positive association with a low density of grass-vegetation were also found (Fillinger et al. 2004). It is conceivable that water surfaces abundantly covered by floating vegetation result in reduced *Anopheles* larval densities – as observed in our study – because of shadowing by the vegetation cover. Different results have been reported by (Savage et al. 1990), where dense vegetation cover by *Lemna* sp. favoured oviposition of *An. albimanus*.

We observed co-occurrence of the *Anopheles* and *Culex*, particularly in rice plots and irrigation wells. Previous work in rural western Kenya also reported the co-occurrence of these two genera of mosquitoes (Fillinger *et al.* 2004; Minakawa *et al.* 1999). We suggest that the occurrence of water insects and tadpoles at low densities may represent an indirect indicator for the presence of larvae, which has been speculated before (Herrel et al. 2001). Larval mortality rates are regulated by intensity of predation (Carlson *et al.* 2004; Mutero *et al.* 2000; Service 1977), and a low density of water insects and predators may indicate micro-habitats that foster larval development. Large permanent habitats, including rice paddies, represent highly dynamic environments, since with plant growing and shadowing modification, micro-ecological conditions alter, and subsequently regulate intra- and inter-specific competition (Chandler et al. 1975; Service 1977).

Sites with turbid water, which were preferentially used by *Anopheles* larvae and pupae, were significantly more often found in the rainy season than in the dry season, most probably because water was repeatedly churned up due to heavy rains. Our observations confirm previous studies that reported increasing water turbidity in naturally formed puddles, as the rainy season progressed (Gimnig et al. 2001). Larvae may develop well in turbid water, particularly in sites in close proximity to maize plants, as maize pollens provide a food source for *An. arabiensis* (Ye-Ebiyo et al. 2003). In the town of Man, maize plants were widespread not only in agricultural zones, but also in domestic backyards and home gardens.

Contrary to our expectations, the presence of dense waste did not affect negatively the presence and density of *Anopheles* larvae and pupae. Assuming that breeding sites within the agricultural zones, where human population densities are high, are more likely to be exposed to waste than untouched breeding sites, we suspect that larvae may be adapting progressively to man-made environments, because larvae populate also polluted sites which has also been observed elsewhere (Sattler et al. 2005).

Effect of agricultural land use

Large variations in the frequency of *Anopheles* observed between the different agricultural zones, which are probably related to patterns of agricultural land use that create various breeding habitats by different types of man-made water bodies, were already articulated before (Conn *et al.* 2002; Okogun *et al.* 2005; Tadei & Dutary Thatcher 2000). In contrast, no association between the occurrence of water bodies and farming activities around domestic areas are reported in Malindi, Kenya (Keating et al. 2004). In our study, the following key results underscore the underlying factors for an undisturbed larvae production in our sites: (i) high frequencies of *Anopheles* larvae in both seasons in zones containing large rice perimeters, (ii) large variations of larvae in mixed vegetable-rice zones, and (iii) a high frequency of pupae in the dry season. These preliminary results need to be further validated and tightened for malaria vectors, since distance from breeding sites to human habitations is an important determinant for malaria transmission patterns, as observed in an urban setting of Uganda (Staedke et al. 2003). In the town of Man, the estimated mean distance between cultivated areas and farmers' houses was in general 100 m or less, and the estimated density of habitations between 40 and 80 houses per ha. Possible associations between proximity of farmers' houses and specific breeding sites are currently being analysed and will be discussed in detail elsewhere. Risk mapping of spatio-temporal distribution of *Anopheles* breeding sites at small scales would be a further step to identify high risk areas and can guide environmental control measures (Keating *et al.* 2003; Ribeiro *et al.* 1996).

The burden of malaria can be significantly reduced by environmental management strategies, including water and vegetation management (e.g. intermittent irrigation of rice paddies) and maintenance of irrigation schemes (Keiser *et al.* 2005; Keiser *et al.* 2002; Senzanje *et al.* 2002; Utzinger *et al.* 2001). However, extensive water management is effective only if surfaces are completely drained and temporary puddles reduced, otherwise they can provide attractive larval habitats (Mutero et al. 2000). Potential effects of fertilizers and chemical treatments in rice fields and vegetable gardens on larval development warrants detailed investigation in future studies.

In conclusion, urban agricultural land use and agricultural activities in medium-sized towns can create favourable conditions for the proliferation of mosquito breeding sites and malaria vector diversity. Our results indicate that productive *Anopheles* breeding sites were related to specific man-made habitats, most notably rice paddies, agricultural trenches and irrigation wells. Immature stages are easier to control than adult mosquitoes, since they are bound to water bodies and related to areas of human domestic and agricultural activities. Our findings provide leverage to consider environmental management for malaria control in urban settings, as there are relatively few highly productive and man-made habitats where larval development occurs. This requires enhanced knowledge on spatio-temporal dynamics of breeding sites and micro-ecological habitat characteristics.

5.6 Acknowledgments

We thank Mr. D. Doua and his assistants (Mr. S. Tokpa and Mr. M. Kpan) for help during the breeding site assessments. We also thank Mr. M. Sattler for useful comments during the conceptualisation of the appraisal form. This investigation received financial support from the Swiss National Foundation through an SNF-Förderungsprofessur to J. Utzinger (project no. PPOOB--102883) and the National Centre of Competence in Research (NCCR) North-South program entitled “Research partnerships for mitigating syndromes of global change”, individual project 4 (IP4), entitled “Health and well-being” and the Swiss Development Cooperation (SDC) through its project at the CSRS “Contribution to the process of national reconciliation in Côte d’Ivoire”. The manuscript benefited from valuable comments put forth by two anonymous referees.

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6. Urban farming and malaria risk factors in a medium-sized town in Côte d'Ivoire

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This article has been published in:
American Journal of Tropical Medicine and Hygiene (2006), **75** (6): 1223-1231

6.1 Abstract

Urbanization occurs at a rapid pace across Africa and Asia and impacts people's health and well being. A typical feature in urban settings of Africa is the maintenance of traditional livelihoods, including agriculture. The purpose of this study was to investigate malaria risk factors in urban farming communities in a medium-sized town of Côte d'Ivoire. Two cross-sectional surveys were carried out among 112 households from six agricultural zones. First, the heads of households were interviewed on agricultural land use, farming practices, water storage, sanitation facilities, and socio-economic status. Second, a finger prick blood sample was taken from all household members and examined for the occurrence and density of *Plasmodia*. Geographic coordinates of houses, farming plots, and potential mosquito breeding sites were recorded and integrated into a geographic information system. Predictors of *Plasmodium falciparum* parasitemia were assessed using non-random and random effects Bayesian regression models. The overall prevalence of *P. falciparum* was 32.1%. In children aged < 15 years, risk factors for a *P. falciparum* infection included living in a specific agricultural zone, close proximity to permanent ponds and fish ponds, periodic stays overnight in temporary farm huts, and low socio-economic status. Our findings indicate that specific crop systems and specific agricultural practices may increase the risk of malaria in urban settings of tropical Africa.

Key words

Malaria, *Plasmodium falciparum*, urban agriculture, medium-sized town, crop systems, farming practices, mosquito breeding sites, Bayesian regression models, Côte d'Ivoire

6.2 Introduction

Malaria delays the socio-economic development of affected regions, and is a major roadblock on the path toward achieving several of the targets embodied in the Millennium Development Goals, particularly in sub-Saharan Africa (Sachs & Malaney 2002; Snow *et al.* 2005; Worrall *et al.* 2005). The process of urbanization alters ecologic and socio-cultural diversity (Nunan & Satterthwaite 1999), and often leads to enhanced spatio-temporal heterogeneities at a small scale (Luck & Jianguo 2002; Utzinger & Keiser 2006). Urban malaria is a common, albeit under-researched topic, and thus needs targeted focus. Important considerations for understanding the epidemiology of urban malaria include the high rate of population growth in urban settings (Hay *et al.* 2005; Keiser *et al.* 2004), the lack of acquired immunity among urban inhabitants (Castro et al. 2004), the possibility that malaria vectors may adapt to urban ecosystems (Chinery 1984), and the maintenance of rural lifestyles and livelihoods once populations have migrated to and settled in urban areas (Carrasquilla 2001; Keating et al. 2003). Epidemiological studies on urban malaria in sub-Saharan Africa have focused primarily on large cities; e.g., Brazzaville in Congo (Trape & Zoulani 1987), Abidjan in Côte d'Ivoire (Wang et al. 2006), and N'Djamena in Chad (Othnigué *et al.* 2006). To date, only few studies investigated malaria risk factors in small- and medium-sized towns in Africa (Matthys *et al.* 2006). Compared to mega-cities, population densities are usually lower, and there are larger open green spaces in smaller towns.

Farming represents an important livelihood strategy for a considerable number of urban dwellers. However, urban farmers are often marginalized and not officially recognized by the national authorities (Nugent 2000). Urban agriculture has been defined as "the production, processing and distribution of a diversity of foods, including vegetables and animal products in intra-urban or at peri-urban areas" (Baumgartner & Belevi 2001). It is important to note that specific types of agricultural land use in urban settings may create suitable mosquito breeding sites and thus increase the risk of malaria, which in turn can affect agricultural land use patterns and household income (Wang'ombe & Mwabu 1993). For example, in an intensive vegetable farming zone in a small town of central Côte d'Ivoire, malaria accounted for more than half of the work days lost, which significantly reduced yields and revenues (Girardin et al. 2004).

The objectives of the study presented here were to identify risk factors for malaria among urban farmers and their families in a medium-sized town of Côte d'Ivoire, and to investigate whether the prevalence and intensity of *P. falciparum* infections are associated with the distance between specific human-made water bodies and the location of farmers' houses. This study complements our previous work that focused on agricultural land use and mosquito larval habitats in the same town (Matthys *et al.* 2006).

6.3 Materials and methods

Study area

Our study was carried out between April 2004 and June 2005 in Man, a district town in Côte d'Ivoire, which is 630 km northwest of the economic capital Abidjan. Entomologic studies in the western forest zone of Côte d'Ivoire identified *Anopheles gambiae s.l.* and *An. funestus* as the key malaria vectors (Adja *et al.* 2006; Betsi *et al.* 2003; Nzeyimana *et al.* 2002). In a previous community-based cross-sectional survey in a village 25 km east of Man, the prevalence of *P. falciparum* was 76.4% (Raso *et al.* 2004).

According to the 1998 census, the population of Man was estimated at 115,000 (data from the Institut National de la Statistique). Approximately 30% of the households are engaged in subsistence agriculture. Trade (up to one-third), day labor and handcraft served as the main income-generating activities (Action Contre la Faim; unpublished data). Patches of irrigated agricultural plots, mainly rice paddies and vegetable gardens, are concentrated in the southwestern part along the banks of the Kô River and in lowlands (Matthys *et al.* 2006).

Agricultural zones, farming households and questionnaire surveys

Seven agricultural zones were identified in April 2004, all characterized by the presence of irrigated crop systems (Matthys *et al.* 2006). The zones are located within an area of 5 x 7 km. Mixed crops are typical for zones 1 and 3, rice is grown in traditional smallholder plots in zones 4 and 6, and a large rice perimeter is found in zones 5 and 7, with traditional smallholder irrigated rice also present in zone 7. Logistic reasons precluded our planned survey in zone 2; thus no data are presented for this zone.

Farmers were identified during work by our team of five field workers when visiting agricultural zones at different day times during six consecutive days. The same method was previously used in a study on health-related issues of urban agriculture in Ouagadougou, Burkina Faso (Cissé 1997). The two inclusion criteria for a household were (i) farming is the main occupation, and (ii) farming in the actual zone has been done for at least one year.

After explaining the purpose of our study and receiving oral consent from the household heads, a list of all household members was established, including their name, age, and sex. We defined a member of a household as a person who lived in the household for at least nine months, and who shared meals and income. A total of 131 farming households (with an estimated 1164 individuals) and 34 control households (with an estimated 272 individuals) were invited to participate in the study. In October 2004, a questionnaire was administered to all household heads to investigate agricultural land use patterns, including crop types, storage and use of water at home and on agricultural plots, livestock ownership, and agricultural activities. In June 2005, heads of households were interviewed on their socio-economic status, including questions on education attainment, housing characteristics, asset ownership, sanitation facilities, and personal protection against mosquito bites. This was coupled with a cross-sectional malariologic survey as detailed below. Geographic coordinates of each house and the main agricultural plots were collected, using a hand-held global positioning system receiver (Garmin eTrex and 12XL, Garmin International Inc.; Olathe, USA).

Field and laboratory investigations

The protocol for our cross-sectional malariologic survey was approved by the institutional review boards of the Swiss Tropical Institute (Basel, Switzerland) and the Centre Suisse de Recherches Scientifiques (Abidjan, Côte d'Ivoire), and received ethical clearance from the Ministry of Public Health in Côte d'Ivoire. Convenient meeting places were chosen in the different zones, e.g., community building, empty classroom, or yard of a political or religious leader. All members of the selected households were invited to provide a finger prick blood sample.

Thick and thin blood smears were prepared on microscope slides. They were air-dried and transferred to the community health laboratory of Man, where they were stained with Giemsa, following routine procedures. Within four weeks, the slides were read under a light microscope for the presence and density of *Plasmodia* parasitaemia by an experienced laboratory technician, assuming for a standard white blood cell count of 8,000/µl of blood. For quality control purposes, a random sample of 70 (8.7%) of 809 slides was cross-checked by another senior technician. An accuracy rate of 89% was noted, which was considered sufficient to use the data for subsequent analyses.

Individuals who reported malaria symptoms at the time of finger prick blood sampling were diagnosed by an experienced nurse. An antimalarial (i.e., amodiaquine) was administered to those with a confirmed diagnosis, according to national guidelines.

Data management and statistical analysis

All data were double-entered and cross-checked, using version 3.1 of EpiData software (EpiData Association; Odense, Denmark). Statistical analyses were carried out with Stata version 9 software (Stata Corporation; College Station, TX, USA) and WinBUGS version 1.4.1 (Imperial College & Medical Research Council, London, United Kingdom). Maps with the location of the farmers' houses and agricultural plots were established in ArcMap™ version 9.0 (Environmental Systems Research Institute, Redlands, CA, USA). Nearest straight-line distances between farmers' houses and the Kô River and other potential mosquito breeding sites were calculated in ArcMap™ and classified as 0-99 m, 100-499 m, and ≥ 500m (Staedke et al. 2003).

Study participants were grouped into six age classes: < 5, 5-9, 10-14, 15-24, 25-39, and ≥ 40 years (Raso *et al.* 2004). Three infection intensity categories for *P. falciparum* were considered: light infection (1-50); moderate infection (51-500); and heavy infection (> 500) parasites/µl of blood (Raso *et al.* 2004).

An index of housing characteristics (e.g., type of wall) and assets owned (e.g., bicycle) was used to calculate the household socio-economic status through principal component analysis. Wealth quintiles were derived from the first principal component (PC) (Filmer & Pritchett 2001). The method was adapted to the local context of Man, as described elsewhere (Raso et al. 2005).

Pearsons' chi-square test and Fisher's test as appropriate were applied to compare proportions between groups. Risk factors for prevalence and intensity of *P. falciparum* infection were investigated, using bivarite logistic and negative binomial regression models, respectively. Potential interactions between different variables and age, socio-economic status and agricultural zone were assessed using the likelihood ratio test. For the variable "periodic stay overnight at farming huts", we tested for interactions with all variables.

Explanatory variables significant at a 15% significance level were chosen to enter into Bayesian multiple (logistic and negative binomial) regressions. Between-household variation (σ_1^2) was taken into account by introducing in the model household-specific random effects with an exchangeable correlation structure. Similarly, geographic correlation was modeled via location-specific random effects. We assumed that spatial correlation is an exponential function of the distance, i.e., $\sigma_2^2 \exp(-\rho d_{kl})$, where d_{kl} is the straight-line distance between households *k* and *l*, σ_2^2 is the geographic variability known as the sill and ρ is a smoothing parameter that controls the rate of correlation decay with distance. The range of geographic dependency that is the minimum distance at which spatial correlation between locations is below 5% was calculated as $3/\rho$ and expressed in meters.

We tested two different multiple regression models for *P. falciparum* infection prevalence and intensity. Whereas the first model did not take into account the spatial correlation and between-household variation, the second model considered both geographic correlation and between-household variation. Inference was based on the better fitting model, which was selected using the deviance information criterion (DIC) as a goodness of fit measure. The model with the smallest DIC was considered as the best fitting one. Further details on model specifications and model fit are given in the Appendix.

6.4 Results

Profiles of urban farmers in the town of Man

Overall, 672 individuals participated in the cross-sectional studies. Ninty-eight (14.6%) were dropped, because they lacked either demographic data or finger prick blood samples (n = 89), or questionnaire data (n = 9). Thus, our final study cohort consisted of 574 individuals from 112 farming households (zone 1 = 63 individuals and 15 households, zone 3 = 75 individuals and 16 households, zone 4 = 57 individuals and 13 households, zone 5 = 128 individuals and 25 households, zone 6 = 168 individuals and 31 households, and zone 7 = 83 individuals and 12 households). There were 247 children less than 15 years of age (43.0%). The mean age of our study cohort was 23.6 years (SD) = 18.5 years) and the study population showed a similar age distribution as that of the country. The male-to-female ratio was 1:1.1 with no statistically significant difference between age groups. One-third of the households were inhabited by ≥ 10 people. Most urban farmers were from the region of Man, and one-fourth were immigrants from neighboring countries (i.e., Burkina Faso and Mali). Two-thirds of all household heads were illiterate. One of eight farmers had received agricultural training, mainly in rice cultivation and irrigation techniques, which was provided by the national agricultural research center or extension services. Of all households engaged in agriculture, 82.1% reported farming as their only occupation.

Land property status and livestock

Two-thirds of the farmers cultivated their crops on the current plots for at least 5 years. Three-quarters of the farmers worked in the zone where they resided. Half of the farmers rented the land and half were “owners” by purchase or inheritance. We have reported the main crop types in this study area (Matthys *et al.* 2006). Crop systems were primarily rice- and vegetable-based. In addition, rain-fed food crops, particularly manioc, banana and maize, were cultivated. Nearly 60% of the households had some livestock (e.g., cattle, fowls, goats, pigs and sheep). One of eight households maintained fish ponds for aquaculture production.

Socio-economic status

Wealth quintiles derived from an ensemble of household characteristics and assets owned were calculated. The first PC explained 25.9% of the overall variability. Households in possession of a car had the highest score (1.09), followed by those with a video player (0.96). The lowest scores were attributed to households without electricity (-0.87), and without a radio (-0.49). Although electricity was available in all households belonging to the four wealthiest quintiles, only 53.9% of the poorest households were connected to the power grid. Radio was the most frequently owned electronic equipment (64.3%), followed by television (49.1%) and ventilator (33.1%). Mobile telephones and refrigerators were considerably more common in less poor households, and ownership of a video or a car was restricted to the richest quintile. Bed net ownership increased with socio-economic status; only 3.9% of the poorest quintile had a bed net, whereas the respective percentage in the richest quintile was 47.6%. More than one-third of the two poorest quintiles lacked any kind of sanitation facility, but almost all of the two richest quintiles had a latrine.

Plasmodium falciparum **parasitemia in relation to socio-demographic characteristics**

Overall, 184 individuals were infected with *P. falciparum*, resulting in a prevalence of 32.1% (95% confidence interval [CI] = 28.2-35.9). One person had a mixed infection with *P. falciparum* and *P. malariae*. Prevalence and intensity of infection were significantly associated with age ($\chi^2 = 83.5$; degrees of freedom [df] = 5; $P < 0.01$ for prevalence; $\chi^2 = 97.9$; df = 10; $P < 0.01$ for intensity) (Figure 6.1), but not with sex. In children < 10 years of age, the prevalence of *P. falciparum* was 51.8%, whereas significantly lower prevalences were observed in older age groups (25.0% and 10.7% in people 15-24 and 25-39 years of age, respectively). Among those people who were infected, 11.4% had a light infection intensity (mean parasitemia: 48.0 parasites/µl of blood), 47.3% had a moderate infection intensity (mean parasitemia: 188.9, parasites/µl of blood), and 41.3% had a heavy infection intensity (mean parasitemia: 1,221.3 parasites/µl of blood). There were 12 individuals (6.5%) with an infection intensity > 5,000 parasites/µl of blood and their mean parasitemia was 13,575.0 (95% CI = 6,966.4-20,173.6 parasites/µl of blood).

Prevalence or intensity of *P. falciparum* infections were not significantly related to the last reported malaria or fever episode (“hot body”) when using a recall period of 4 weeks. Similarly, sleeping under a bed net during the last night, or the presence of livestock showed no statistically significant association with the presence or density of *P. falciparum*. However, infection intensities were significantly related to wealth quintiles ($\chi^2 = 16.2$, df = 8; $P = 0.04$). The highest frequencies of heavy infection intensities were observed in the quintiles “very poor”, “poor”, and “less poor” (15.8-16.3%), whereas the lowest frequency of heavy infection intensity was observed among the least poor (5.8%).

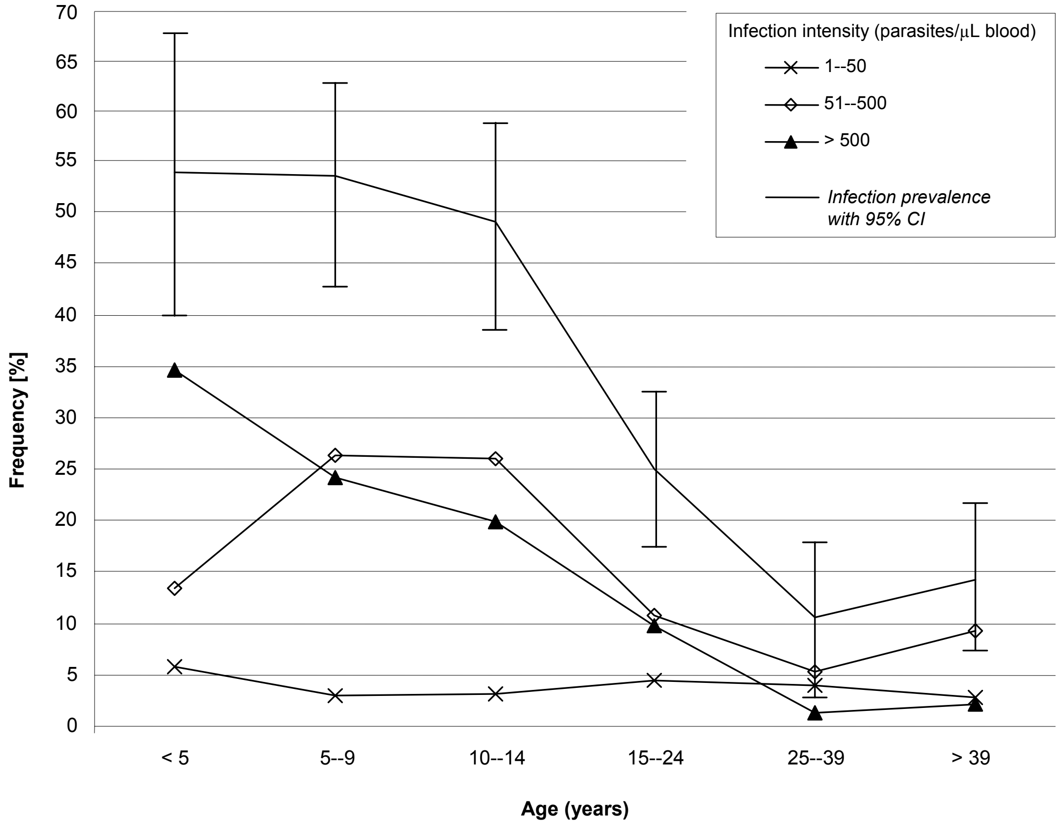

Figure 6.1 Age-prevalence curve of *Plasmodium falciparum* stratified by three classes of infection intensity (n = 574 participants)

Malaria in relation to agricultural zones

Figure 6.2 shows the prevalence and intensity of *P. falciparum* infection for children less than 15 years of age stratified by agricultural zone. There was a statistically significant difference in the prevalence between zones (χ^2 = 26.9, df = 5, P < 0.01). The lowest prevalence of 20.5% (95% CI = 7.3-33.8%) was observed in zone 7 (traditional smallholder rice plots and large rice perimeter) and the highest prevalence of 77.8% (95% CI = 63.5-92.0%) was found in zone 3 (mixed crop systems). Intermediate prevalence levels were observed in zone 5 (60.9%, large rice perimeter, zone 1 (54.8%, mixed crop systems), and zones 4 and 6 (50.0% and 49.3%, respectively; traditional smallholder irrigated rice areas). With regard to infection intensity, similar observations were made as for the spatial distribution of *P. falcipaurm* prevalence; the highest frequency of heavy infections was found in zone 3 (39.0%), whereas no heavy infections were recorded in zone 7.

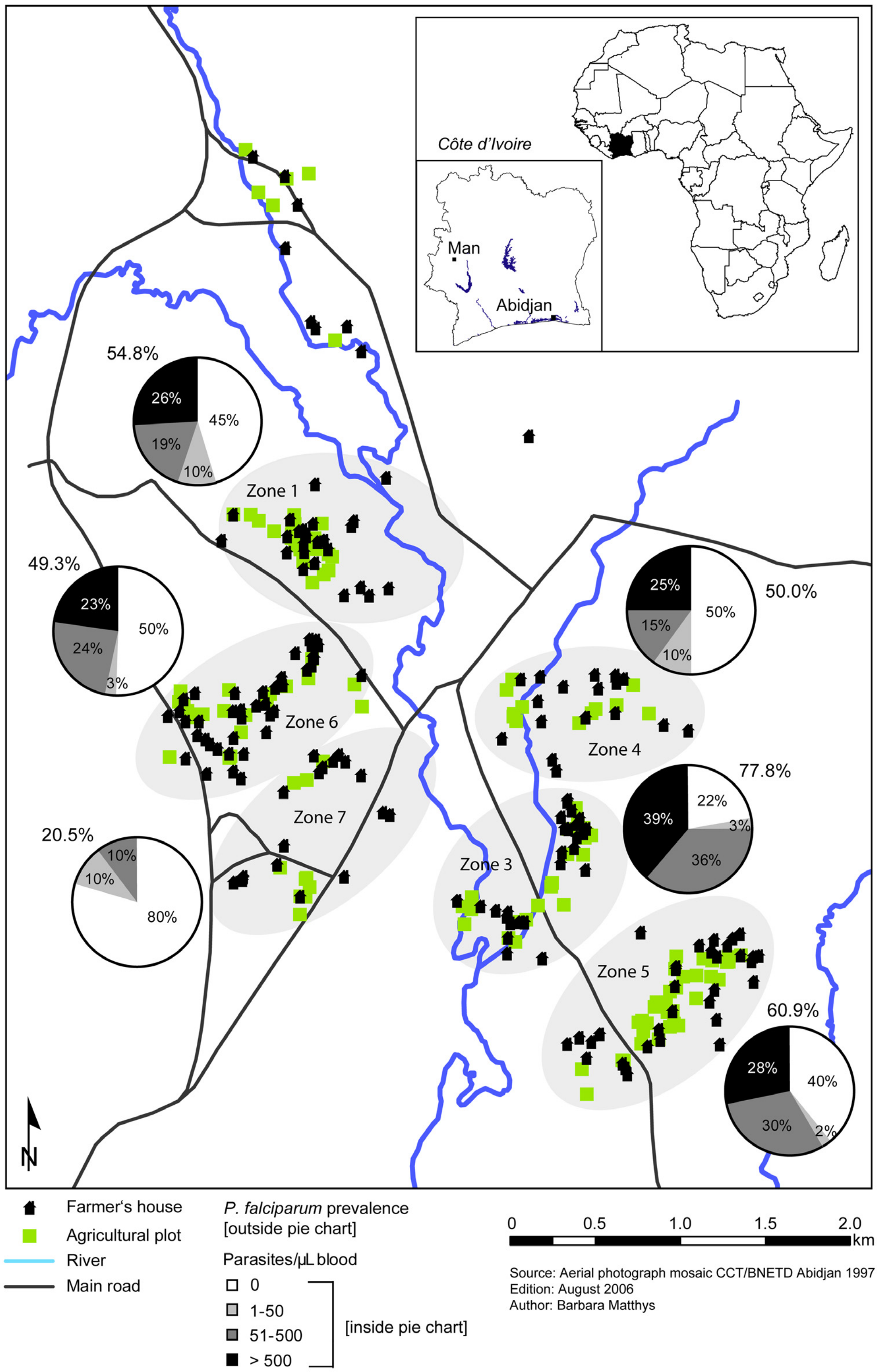

Figure 6.2 Spatial distribution of prevalence and intensity of *Plasmodium falciparum* infection among children <15 years of age (n = 247), stratified by agricultural zone in Man in western Côte d'Ivoire, June 2005

Malaria in relation to distance to potential mosquito breeding sites

Table 6-1 summarizes the results of prevalence and intensity of *P. falciparum* infections in relation to distance to potential mosquito breeding sites for all age groups. Household members residing at least 500 m away from ponds and fish ponds were at a significantly lower risk of a *P. falciparum* infection than those living within 100 m (odds ratio [OR] = 0.47, 95% CI = 0.22-0.99). Intensity of infection decreased with distance to ponds and fish ponds (*P. falciparum* density ratio [*Pf*DR] = 0.36, 95% CI = 0.16-0.82 for 100-499 meters). We found no statistically significant difference between a *P. falciparum* infection and distance to any of the other potential mosquito breeding sites investigated.

Malaria risk factors

Tables 6-2 and 6-3 summarize demographic, socio-economic and agricultural risk factors for *P. falciparum* infection. Results are presented for all age groups and children only (< 15 years of age). With regard to children, those living in zones 3, 4, and 5 were at a significantly higher risk of parasitemia when compared to children living in zone 1 (OR = 32.00, 95% Bayesian Credible Interval [BCI] = 3.97-128.10 for zone 3; OR = 8.77, 95% BCI = 1.04-34.53 for zone 4; and OR = 4.96, 95% BCI = 1.16-14.38 for zone 5). Children residing in zone 7 were 4.3-times less likely to have high levels of parasitemia (*Pf*DR = 0.23, 95% BCI = 0.02-0.95) compared to children living in zone 1. Likewise, children from wealthier households were at lower odds of a *P. falciparum* infection than their poorer counterparts (OR = 0.16, 95% BCI = 0.03-0.46 for children in the poor category).

Another important risk factor for a *P. falciparum* infection was distance to permanent ponds and fish ponds. Children living at least 500 m away from such water bodies were significantly less likely to be infected than those living in close proximity (OR = 0.25, 95% BCI = 0.05-0.72). However, distance did not have any effect on infection intensity among children.

Staying overnight in temporary farm huts was associated with an over 17-fold higher risk of a *P. falciparum* infection when compared to those children from families coming home at night. Malaria infection was not significantly age-related for farming families who periodically stayed overnight in temporary farm huts in contrast to families who stayed home at night.

Table 6-1 Results of bivariate logistic and binomial regression models, including all ages (n = 574)*

Distance to potential mosquito breeding sites (m)	Number (%)	Infection prevalence of *P. falciparum*				Infection intensity of *P. falciparum*			
		OR	95% CI	LRT	*P*-value	*Pf*DR	95% CI	LRT	*P*-value
Pond and fish pond									
0-99	217 (37.8)	1.00				1.00			
100-499	309 (53.8)	0.80	0.55, 1.16			0.36	0.16, 0.82		
≥ 500	48 (8.4)	0.47	0.22, 0.99	4.62	0.010	0.28	0.06, 1.19	7.04	0.030
Rice paddy									
0-99	281 (48.9)	1.00				1.00			
100-499	276 (48.1)	1.06	0.74, 1.51			1.44	0.66, 3.16		
≥ 500	17 (3.0)	0.66	0.21, 2.09	0.72	0.696	1.10	0.11, 11.20	0.83	0.659
Creek/source									
0-99	12 (2.1)	1.00				1.00			
100-499	159 (27.7)	0.78	0.24, 2.58			0.27	0.02, 4.34		
≥ 500	403 (70.2)	0.61	0.19, 1.95	2.11	0.348	0.17	0.01, 2.60	3.49	0.175
Irrigation well									
0-99	228 (39.7)	1.00				1.00			
100-499	333 (58.0)	0.77	0.54, 1.10			1.81	0.82, 4.02		
≥ 500	13 (2.3)	0.81	0.24, 2.70	2.09	0.352	1.64	0.12, 23.06	2.05	0.359
Agricultural trench									
0-99	139 (24.2)	1.00				1.00			
100-499	352 (61.3)	0.86	0.57, 1.30			1.89	0.75, 4.77		
≥ 500	83 (14.5)	0.53	0.28, 0.98	4.42	0.110	0.55	0.16, 2.00	4.51	0.105
Kô River									
0-99	53 (9.2)	1.00				1.00			
100-499	213 (37.1)	0.65	0.35, 1.22			0.32	0.08, 1.33		
≥ 500	308 (53.7)	0.72	0.40, 1.32	1.74	0.418	0.82	0.21, 3.21	5.03	0.081

* Outcomes were presence and intensity of *P. falciparum* infection. The explanatory variable was distance to potential mosquito breeding sites.

OR = crude odds ratio; CI = confidence interval; LRT = likelihood ratio test; *Pf*DR = crude *P. falciparum* density ratio; *P*-value based on LRT

Table 6-2 Results of bivariate logistic regression models and multivariate non-random effects logistic regression models for all ages and children <15 years of age*

	All ages				All ages		Children < 15 years of age	
		Bivariate model			Multivariate models without random effects			
Explanatory variables	No. infected/no. investigated (%)	OR	95% CI	*P*-value	OR	95% BCI	OR	95% BCI
Demography								
Sex[a]								
Male	92/277 (33.2)	1.00						
Female	92/297 (31.0)	0.90	0.64, 1.28	0.566				
Age (years)								
< 5	28/52 (53.9)	1.00			1.00		1.00	
5-9	53/99 (53.5)	0.98	0.50, 1.94		1.06	0.46, 2.11	0.88	0.35, 1.83
10-14	47/96 (49.0)	0.82	0.42, 1.62		0.78	0.33, 1.56	0.64	0.25, 1.33
15-24	28/112 (25.0)	0.29	0.14, 0.57		0.23	0.09, 0.45		
25-39	8/75 (10.7)	0.10	0.04, 0.26		0.07	0.02, 0.17		
≥ 40	20/143 (14.3)	0.14	0.07, 0.29	< 0.001	0.09	0.04, 0.19		
Socio-economic status								
Poorest	42/139 (30.2)	1.00			1.00		1.00	
Very poor	43/138 (31.2)	1.04	0.63, 1.74		0.83	0.40, 1.55	1.09	0.38, 2.47
Poor	34/95 (35.8)	1.29	0.74, 2.24		0.38	0.15, 0.78	0.16	0.03, 0.46
Less poor	43/98 (43.9)	1.81	1.05, 3.09		1.54	0.66, 3.08	4.13	0.99, 11.89
Least poor	22/104 (21.2)	0.62	0.34, 1.12	0.001	0.48	0.20, 0.97	0.41	0.10, 1.14
Agricultural zone								
1 (mixed crops)	29/63 (46.0)	1.00			1.00		1.00	

3 (mixed crops)	33/75 (44.0)	0.92	0.47, 1.81		1.33	0.46, 3.05	32.00	3.97, 128.10
4 (traditional smallholder plot)	13/57 (22.8)	0.35	0.16, 0.77		1.01	0.29, 2.55	8.77	1.04, 34.53
5 (large rice perimeter)	46/128 (35.9)	0.66	0.36, 1.21		1.31	0.55, 2.68	4.96	1.16, 14.38
6 (traditional smallholder plot)	53/168 (31.6)	0.54	0.30, 0.98		0.46	0.15, 1.09	1.38	0.23, 4.54
7 (traditional smallholder plot plus large rice perimeter)	10/83 (12.1)	0.16	0.07, 0.37	< 0.001	0.21	0.06, 0.53	0.49	0.07, 1.69
Cultivated crop type								
Vegetables in market gardens	122/346 (35.3)	1.46	1.01, 2.10	0.042	0.98	0.52, 1.66	1.02	0.40, 2.15
Rain-fed food crops (manioc/maize)	84/229 (36.7)	1.42	0.99, 2.03	0.054	1.27	0.70, 2.11	1.77	0.69, 3.79
Perennials (coffee/cocoa/oil palm)	4/25 (16.0)	0.39	0.13, 1.15	0.062	0.19	0.03, 0.60	0.20	0.01, 0.89
Irrigated and/or rain-fed rice	138/423 (31.0)	0.81	0.54, 1.23	0.322	0.75	0.34, 1.43	0.17	0.03, 0.51
Staying overnight in temporary farm hut	19/30 (63.3)	3.97	1.84, 8.52	< 0.001	14.80	3.23, 45.18	17.05	1.59, 75.88
Distance to permanent ponds and fish ponds (m)								
0-99	78/217 (35.9)	1.00			1.00		1.00	
100-499	96/309 (31.1)	0.80	0.56, 1.16		0.56	0.22, 1.17	1.12	0.30, 2.97
≥ 500	10/48 (20.8)	0.47	0.22, 0.99	0.010	0.36	0.13, 0.80	0.25	0.05, 0.72
DIC					605.66		326.11	

* The outcome was presence of *P. falciparum* infection. Explanatory variables were demographic, socio-economic and agricultural parameters.

OR = crude odds ratio; CI = confidence interval; BCI = Bayesian credible interval; DIC = deviance information criterion; *P*-value based on LRT; [a] Sex not included into the multivariate model; DIC = deviance information criterion

Table 6-3 Results of bivariate binomial regression models and a multivariate random effects binomial regression models for all ages and children <15 years of age*

Explanatory variables	All ages			All ages		Children < 15 years	
	Bivariate model			Multivariate models with household- and location-specific random effects			
	*Pf*DR	95% CI	*P*-value	*Pf*DR	95% BCI	*Pf*DR	95% BCI
Demography							
Sex[a]							
Male	1.00						
Female	1.11	0.51, 2.41	0.796				
Age (years)							
< 5	1.00			1.00		1.00	
5-9	0.93	0.20, 4.30		1.01	0.12, 3.82	0.51	0.10, 1.47
10-14	0.34	0.07, 1.56		0.33	0.04, 1.18	0.26	0.06, 0.74
15-24	0.23	0.05, 1.03		0.17	0.02, 0.64		
25-39	0.26	0.05, 1.32		0.02	0.00, 0.12		
≥ 40	0.05	0.01, 0.21	< 0.001	0.01	0.00, 0.04		
Socio-economic status[a]							
Poorest	1.00						
Very poor	2.07	0.68, 6.29					
Poor	1.46	0.43, 5.03					
Less poor	1.11	0.33, 3.77					
Least poor	1.58	0.48, 5.26	0.754				
Agricultural zone							
1 (mixed crops)	1.00			1.00		1.00	
3 (mixed crops)	1.77	0.37, 8.42		0.79	0.05, 3.50	4.30	0.34, 18.86
4 (traditional smallholder plot)	2.00	0.38, 10.62		0.30	0.02, 1.39	2.48	0.13, 12.28

5 (large rice perimeter)	1.05	0.26, 4.32		1.21	0.13, 4.49	1.16	0.13, 4.46
6 (traditional smallholder plot)	1.30	0.34, 5.00		0.52	0.05, 2.03	0.54	0.04, 2.20
7 (traditional smallholder plot plus large rice perimeter)	0.16	0.03, 0.73	0.067	0.09	0.01, 0.40	0.23	0.02, 0.95
Storage of water in clay pots	2.43	1.12, 5.29	0.032	3.62	1.02, 9.00	1.96	0.53, 5.03
Distance from ponds and fish ponds (m)							
0-99	1.00			1.00		1.00	
100-499	0.36	0.16, 0.82		0.19	0.02, 0.69	0.93	0.14, 3.32
≥ 500	0.27	0.06, 0.19	0.030	0.63	0.08, 2.33	0.56	0.05, 2.24
σ_1^2 (median)[b]				0.42	0.06, 2.13	0.20	0.04, 0.96
σ_2^2 (median)[b]				0.37	0.04, 2.00	0.19	0.04, 0.96
τ_1 [c]				4.15	0.47, 17.75	5.07	1.04, 26.51
τ_2 [c]				4.58	0.49, 20.72	5.19	1.05, 27.05
ρ (median) [d]				0.83	0.08, 4.05	0.76	0.06, 3.85
DIC (total)					3658.21		2459.34

* The outcome was intensity of *P. falciparum* infection. Explanatory variables were demographic, socio-economic and agricultural parameters. *Pf*DR = crude *P. falciparum* density ratio; CI = confidence interval; BCI = Bayesian credible interval; DIC = deviance information criterion; ; *P*-value based on LRT; [a] Sex and socio-economic status not included into the multivariate model; [b] σ_1^2, σ_2^2 = between-household variation, geographic variation; [c] $\tau_1 = 1/\sigma_1^2$, $\tau_2 = 1/\sigma_2^2$; [d] ρ = smoothing parameter

Spatial correlation of malaria infection

The results of the spatial random-effects binomial regression models (Table 6-3) indicate no significant spatial correlation of a *P. falciparum* infection with distance between the farmers' houses. The minimum distance at which spatial correlation between farmers' houses decreased to less than 5% was as low as 3.9 m for children < 15 years of age. This means that for houses located further from each other than this threshold distance, there is no spatial correlation of infection. In the spatial random effects models, the between-household variation equals the spatial variation. Given the extremely low threshold of spatial correlation for intensity of *P. falciparum* infection, and the marginal between-household variation, spatial correlation was not significant.

6.5 Discussion

Our results suggest that the risk of *P. falciparum* infection among farmers and their families in a medium-sized town of Côte d'Ivoire is affected by agricultural land use patterns and common agricultural practices. The prevalence of *P. falciparum* among children less than 15 years of age was 51.8%, and the overall prevalence in all age groups was 32.1%. Residence in a specific agricultural zone appeared as a major risk factor for malaria prevalence and intensity among children. We observed significant spatial heterogeneity, with prevalence of infection ranging between 20.5% (traditional smallholder rice plots and large rice perimeter) and 77.8% (mixed crop systems). Recent studies carried out in large towns of Ghana, namely Kumasi (Afrane et al. 2004) and Accra (Klinkenberg et al. 2005) in Ghana reported highest malaria prevalence and frequency of heavy infections in zones of mixed crop systems. Other prominent risk factors for a *P. falciparum* infection in children in the current study included close proximity to permanent ponds and fish ponds, low socio-economic status, and staying overnight in temporary farm huts. Our study also confirms that *P. falciparum* is the predominant *Plasmodium* species in the western part of Côte d'Ivoire (Nzeyimana *et al.* 2002; Raso *et al.* 2004).

An important limitation of this study is that instead of our initial plans to carry out two cross-sectional malariologic surveys – one during the dry season and the other during the wet season – we were able to conduct only one survey in the transition period between the dry and the rainy season. The principal reason was the socio-political instability in Côte d'Ivoire, which began in September 2002 and was ongoing during our field work (Betsi et al. 2006).

In view of large open green areas and the magnitude of subsistence farming, the latter partially explained by the persisting socio-political crisis, land use pattern in Man show rural characteristics. In a previous study carried out in the town of Bouaké, central Côte d'Ivoire, malaria transmission was high in irrigated rice paddy zones during the rainy season and showed a positive association with water availability in market gardens and with the rice cropping cycle (Dossou-Yovo et al. 1998). Another investigation on malaria transmission dynamics in irrigated rice and vegetable crop systems in a rural setting of central Côte d'Ivoire showed that the density of the main malaria vector (*An. gambiae*) was higher in rice-based crop systems than in vegetable gardens (Koudou et al. 2005). Our broad classification of crop types into market garden, rain-fed food, rice and perennial crops was a too limited indicator for identification of high-risk areas for malaria, given the small scale of our study area (i.e., 5 x 7 km). The issues of pattern and scale are partially responsible for this observation (Levin 1992). However, since specific man-made water bodies have been identified as productive *Anopheles* breeding sites and could be linked to typical crop systems (e.g., irrigation wells in market gardens) (Matthys *et al.* 2006), we conclude that crop type classifications might be useful for larger study areas, particularly in case data on environmental features and land use are provided by high-resolution satellite imagery. The significant association found between *P. falciparum* infection and the distance to ponds and fish ponds might be explained by this type of water body being relatively large and permanent, thus providing more stable conditions for mosquito breeding than smaller, often temporary water bodies (e.g., agricultural trenches or irrigation wells). Moreover, the latter are often disturbed by human activities. Our findings are in agreement with a recent study in Kampala, Uganda, where living in close proximity to a swamp was a risk factor for malaria incidence (Staedke et al. 2003). In another study carried out in Dakar, Senegal, the density of adult *Anopheles* decreased significantly with distance from a swamp (Trape et al. 1992).

Although the number of farmers (n = 15) and children less than 15 years of age (n = 15) who occasionally stay overnight in temporary farm huts was small, this feature was identified as a risk factor for infection with *P. falciparum*. These temporary farm huts are poorly constructed (wood and thatched roofs), unscreened with open eaves, and usually located at the borders of rice fields, and thus surrounded by potential *Anopheles* breeding sites (Matthys *et al.* 2006). The number of overnight stays in temporary farm huts usually peaks during periods of intensive agricultural labor in the main harvest period at the end of the rainy season. This time of the year coincides with the highest number of potential mosquito breeding sites and an elevated risk of malaria transmission (Koudou et al. 2005). Higher *Plasmodia* infection rates among adults who sleep in temporary farm huts or forested areas because of agricultural activities have been observed in southwestern Côte d'Ivoire (Nzeyimana et al. 2002), as well as in Thailand (Somboon et al. 1998), Malaysia (Seng et al. 1999), and Colombia (Sevilla-Casas 1993). In a recent study, an increased risk of malaria was observed among people who periodically spent time outside Abidjan, and hence it was speculated that urban dwellers become infected while spending time away from their place of residence (Wang et al. 2006). These urban-to-rural movements involve often entire families, particularly during harvest and other intensive agricultural work periods. Other reasons include socio-cultural obligations (e.g., attending a funeral), or recreational activities (e.g., spending leisure time in the countryside). Consequently, the issue of human mobility with urban-to-rural movement patterns warrants more attention to enhance our understanding of the epidemiology of urban malaria.

Surprisingly, we could not find any significant association between *P. falciparum* infection and sleeping under an (impregnated) bed net. However, there is evidence from Africa that the use of bed nets reduces the risk of malaria-related morbidity and mortality (Lengeler 2004). Despite the lack of a significant association between *P. falciparum* infection and bed net use in the present study, the higher the socio-economic status of a farming family, the higher the frequency of bed nets owned. However, ownership does not imply regular use. An enhanced understanding of individual bed net usage in the current setting would be useful for adapted community-based prevention approaches. Conversely, our finding of a significant association between socio-economic status and the risk of *P. falciparum* infection is in agreement with a previous study carried out in an urban setting of Ghana (Klinkenberg et al. 2006). A low socio-economic status was associated with low protective housing conditions: i.e., 73.1% of the "poorest" and 63.2% of the "very poor" households inhabited houses with wooden walls sealed up with traditional clay.

Another important aspect of our study originates from the use of non-random effects models, and household-specific and location-specific random effects multivariate models fitted to our data by using Bayesian statistical specifications. One advantage of Bayesian modeling is that spatial correlation of infection can be incorporated (Basáñez et al. 2004). Interestingly, the prevalence of *P. falciparum* was better explained by non-random effects models, whereas infection intensity data showed better fits by random-effects models. However, when spatial correlation was taken into account, agricultural zone remained the only significant covariate in the model focusing on children only. There is a need to test whether intensity might be a more suitable indicator than prevalence to explain spatial heterogeneity at a small scale, where houses are close to each other and malaria prevalence is moderate to high.

In conclusion, *P. falciparum* infection among families engaged in urban farming of a medium-sized town of Côte d'Ivoire were governed by specific types of agricultural land use, farming practices, close proximity to man-made permanent water bodies, and socio-economic status. Bayesian statistical approaches at household level can explain spatial heterogeneity at a small scale. Our study is relevant for the ecologic understanding at the local level, and might be utilized to design and implement prevention strategies and vector control programs that are readily adapted to local agro-ecological settings (Mukabana *et al.* 2006; Utzinger *et al.* 2001; van den Berg & Knols 2006). Risk factors can be identified successfully at community level as mosquitoes and humans interact at this scale. For medium-sized towns in malaria-endemic settings, we propose in-depth studies combining systematic appraisals of man-made mosquito breeding sites (Matthys *et al.* 2006) and repeated mosquito collections (Koudou et al. 2005) in selected agricultural zones that would contribute to a better understanding of malaria transmission patterns and dynamics in zones of urban agricultural land use.

6.6 Appendix

Let Y_{ijk} be the number of *P. falciparum* parasites in individual *k* within household *j* at location *i*. We assume that Y_{ijk} has a negative binomial distribution $Y_{ijk} \sim Nb(\mu_{ijk}, r)$ with mean μ_{ijk} and overdispersion parameter *r*. We modeled the logarithm of the μ_{ijk} as an additive function of various determinants of infection intensity, X_{ijk} (demographic and socio-economic factors, agricultural zone, and distance to potential mosquito breeding sites), the household (u_j) and location-specific random effects (φ_i), which is $\log(\mu_{ijk}) = \underset{\sim}{X}_{ijk}\underset{\sim}{\beta}^T + u_j + \varphi_i$ where $\underset{\sim}{\beta}$ is the vector of regression coefficients.

For modeling the infection status Z_{ijk} of individual *k* within household *j* at location *i*, we assumed that Z_{ijk} follows a Bernoulli distribution, $Z_{ijk} \sim Ber(p_{ijk})$, where p_{ijk} measures the risk of an infection with *P. falciparum* for individual *k* within household *j* at location *i*. We modeled covariates and random effects on the log*it* scale, that is $\log it(p_{ijk}) = \underset{\sim}{X}_{ijk}\underset{\sim}{\beta}^T + u_j + \varphi_i$.

For the multiple regression models (infection prevalence and intensity), we assumed that $u_j \sim N(0, \sigma_1^2), j = 1, \ldots J$ and $\varphi \sim MVN(0, \Sigma)$ where $\Sigma_{rs} = \sigma^2 \exp(-d_{rs} / \rho)$ where d_{rs} is the distance between location *r* and *s*, ρ is the rate of correlation decay, and σ_1^2 and σ_2^2 are the between-household and spatial variation, respectively. We adopted the Bayesian approach to inference and choose vague Normal prior distributions with large variances (i.e., 10,000) for the regression coefficients and gamma prior distributions for ρ, σ_1^2 and σ_2^2. Markov chain Monte Carlo (MCMC) simulation was employed to estimate the model parameters (Gelfand & Smith 1990). We run a single chain sampler with a burn-in of 5,000 iterations. Convergence was assessed by inspection of ergodic averages of selected model parameters. The DIC was used to select the models that best fitted the data (Spiegelhalter et al. 2002).

6.7 Acknowledgments

We thank all farmers and their families for active participation. We acknowledge political and religious leaders, school directors and community youth associations for placing rooms and other infrastructures at our disposal during the questionnaire and malariologic surveys. We are indebted to Mr. D. Doua and his team (Mr. S. Tokpa, Mr. M. Kpan, Mr. C. Gueu Sadia, Mr. R. Dion, Ms. P. Blé Gosamé, Ms. A. Thian Yohan, Ms. S. Sadia) of the Organization for the Development of Women's Activities (ODAFEM) in Man for their commitment to this study. We thank Mr. M. Koné from the Université de Bouaké for help with the socio-economic survey. We are grateful to the laboratory technicians (Mr. A. Allangba, Mr. S. Diabaté, Mr. A. Fondjo, Mr. B. Sosthène and Mr. M. Traoré) and the medical field staff of Man for their high-quality field and laboratory work.

Financial support: This investigation received financial support from (i) the National Centre of Competence in Research (NCCR) North-South program entitled "Research partnerships for mitigating syndromes of global change", individual project no. 4 (IP4), entitled "Health and well-being"; (ii) the Swiss Development Cooperation (SDC) for support granted to the Centre Suisse de Recherches Scientifiques via a project entitled "Contribution to the process of national reconciliation in Côte d'Ivoire", and (iii) the Swiss National Science Foundation (SNF) through a research project to Penelope Vounatsou and Laura Gosoniu (project no. 3252B0-102136), a fellowship to Giovanna Raso (project no. PBBSB-109011), and a 'SNFFörderungsprofessur' to Jürg Utzinger (project no. PP00B--102883).

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7. Risk factors for *Schistosoma mansoni* and hookworm in urban farming communities in western Côte d'Ivoire

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This article has been published in:
Tropical Medicine and International Health (2007), **12** (6): 709-723

7.1 Abstract

OBJECTIVES To identify risk factors for *Schistosoma mansoni* and hookworm infections in urban farming communities, and to investigate small-scale spatial patterns of infection prevalence.

METHODS A cross-sectional survey was carried out in 113 farming households (586 individuals) and 21 non-farming households (130 individuals) from six agricultural zones in the town of Man, western Côte d'Ivoire. Heads of households were interviewed on common agricultural activities, land and water use, education attainment, socio-economic status and sanitation facilities. Household members provided stool specimens that were processed by the Kato-Katz technique and a formol-ether concentration method and diagnosed for *S. mansoni*, hookworms and other soil-transmitted helminths and intestinal protozoa. Bayesian statistics were employed for spatial analyses.

RESULTS The prevalences of *S. mansoni* and hookworm in farming households were 51.4% and 24.7%, respectively. Risk factors for a *S. mansoni* infection comprised living in close proximity to the Kô River, water contact with irrigation wells and ponds and low education attainment. Living in zones of smallholder irrigated rice plots or large rice perimeters, using water from domestic wells, and low socio-economic status were risk factors for a hookworm infection. We found significant spatial heterogeneity between agricultural zones, with the highest infection prevalences of *S. mansoni* and hookworm in the zone where there was a large rice perimeter.

CONCLUSIONS In this urban setting, both *S. mansoni* and hookworm infections were related to specific agricultural activities. Health education and active participation of urban farmers for the control of schistosomiasis and soil-transmitted helminthiasis is recommended.

Keywords *Schistosoma mansoni*, hookworm, risk factors, urban agriculture, Côte d'Ivoire

7.2 Introduction

Soil-transmitted helminthiasis and schistosomiasis are endemic in most regions of the humid tropics (Bethony *et al.* 2006; Gryseels *et al.* 2006). More than one billion people are infected with any of the three major soil-transmitted helminths, namely *Ascaris lumbricoides*, hookworms and *Trichuris trichiura* (Bethony *et al.* 2006; de Silva *et al.* 2003), and an estimated 207 million people are infected with schistosomes (Steinmann *et al.* 2006). The global burden of soil-transmitted helminthiasis might be as high as 39 million disability-adjusted life years (DALYs), and hence approaching that of malaria (Hotez *et al.* 2006; Lopez *et al.* 2006).

Hookworm larvae prefer warm and partially shaded sandy soils, which are common in rural areas of the tropics and poor urban settlements (Brooker *et al.* 2004). An infection with hookworms is accomplished when the unprotected human skin is exposed to such soils (e.g. walking barefoot). Previous studies have shown that hookworm disease is common among farmers and vegetable growers, and is often associated with waste water and night soils that are used to enhance agricultural output (Brooker *et al.* 2004; Ensink *et al.* 2005). Schistosomiasis is typically considered as a rural disease. Transmission occurs when humans contact freshwater bodies infested with cercariae that have been released by intermediate host snails (Gryseels *et al.* 2006). In view of schistosomiasis being closely linked to human water contact patterns, irrigated agriculture plays an important role (Bethony *et al.* 2004; Huang & Manderson 1992; Steinmann *et al.* 2006).

Available data suggest that there is a declining trend in the prevalence of soil-transmitted helminth infections in many parts of the developing world. The causes are multifactorial, including urbanization, economic advancement and abandoning agrarian lifestyles in rural settings (de Silva *et al.* 2003; Hotez *et al.* 2006). However, in many parts of Africa and Asia where urbanization progresses at a rapid pace (Utzinger & Keiser 2006), urban farming has become an important livelihood strategy (Bryld 2003). Urban agriculture is linked with farming-related health issues, for example through domestic and industrial waste disposal, which in turn contaminate soils and water (Amoah *et al.* 2006; Binns *et al.* 2003). Only few studies have investigated the epidemiology of soil-transmitted helminthiasis and schistosomiasis in urban settings (Brooker *et al.* 2006a; Firmo *et al.* 1996; Fournet *et al.* 2004; Ximenes *et al.* 2003). There is a paucity of this kind of investigation focusing on urban farming communities.

In a preceding study, we mapped and characterized productive *Anopheles* breeding sites and investigated risk factors for malaria in urban farmers and their families living in different zones of irrigated crop systems in a district town of western Côte d'Ivoire (Matthys *et al.* 2006a; Matthys *et al.* 2006b). The objectives of this study were (i) to identify risk factors for hookworm and *Schistosoma mansoni* infections in these urban farming communities, and (ii) to assess micro-geographical heterogeneity of infection prevalence, using Bayesian spatial statistics.

7.3 Materials and methods

Study area and population

The study area and the population surveyed have been described before (Matthys *et al.* 2006a; Matthys *et al.* 2006b). In brief, the study was carried out between April 2004 and June 2005 in the town of Man, located in the western part of Côte d'Ivoire. The population of Man is estimated at 115,000 people. One-third of the households are engaged in urban agriculture, primarily along the banks of the Kô River and in small inland valleys in the south-western part of the town. Figure 1 shows the six selected agricultural zones with irrigated crop systems. Zones 1 and 3 consisted of mixed crop systems with vegetable gardens and traditional smallholder rice plots with one cropping cycle per year. Zones 4 and 6 were smallholder rice plots. Zones 5 and 7 consisted of large rice perimeters allowing two cropping cycles. In the latter zone, smallholder rice paddies were also present. Zone 2 is located furthest north at the outskirts of Man. Because of logistical problems, no parasitological survey was carried out in this zone, but questionnaires were pre-tested here.

A total of 131 farming households were identified by directly contacting farmers during their work in the fields (Matthys *et al.* 2006b). We sought oral consent and then collected geographical coordinates of the houses and the main agricultural plots using a hand-held global positioning system (Garmin eTrex and 12XL; Garmin International Inc., Olathe, KS, USA). The name, age and sex of all household members were recorded (n = 1164) and assigned unique identifiers. An additional 34 households not engaged in urban agriculture were randomly selected from the same study area using the EPI survey approach (Lemeshow & Robinson 1985). The estimated population in these non-farming households was 272 people.

Questionnaire surveys

In October 2004, a questionnaire was administered to the heads of the farming households. Questions pertained to agricultural activities and land and water use (Matthys *et al.* 2006b). In June 2005, heads of both farming and non-farming households were interviewed on education attainment, socio-economic status and sanitation facilities. Information was also collected from all household members on common water contact patterns, including types of water bodies contacted (i.e. Kô River, creek, pond, irrigation canal and wells), water-related activities (i.e. swimming/bathing, fetching water for irrigation, cleaning irrigation canals, washing clothes and fishing), and frequency of water contact patterns. As mentioned before, the questionnaires were pre-tested in zone 2. In addition, snail surveys were conducted in all agricultural zones alongside *Anopheles* breeding site assessments that have been described elsewhere (Matthys *et al.* 2006a). Intermediate host snails of *S. mansoni* (i.e. *Biomphalaria pfeifferi*) were transferred to a laboratory at the Université de Cocody-Abidjan, exposed to artificial light and checked for cercarial shedding.

Parasitological survey and laboratory investigations

Field and laboratory procedures have been detailed elsewhere (Matthys *et al.* 2006b). Briefly, each household was visited in the evening, the purpose of the parasitological survey explained and all household members invited to provide a stool specimen. Small plastic containers were handed out for stool collection. The following day, the filled containers were collected, attached with unique identifiers and transferred to a laboratory in Man.

A two-pronged diagnostic approach was employed. Firstly, a small amount of stool (1-2 g) was preserved in a tube filled with 10 ml sodium acetate-acetic acid formalin (SAF). These SAF-preserved stool samples were forwarded to a laboratory in Abidjan. Within 12 months, they were processed by a formol-ether concentration method and examined by experienced laboratory technicians for the presence of *S. mansoni* and soil-transmitted helminth eggs, and cysts or throphozoites of intestinal protozoa (Marti & Escher 1990). Secondly, two Kato-Katz thick smears were prepared from each stool specimen on microscope slides, using 42 mg plastic templates (Katz *et al.* 1972). Slides were cleared for 30-45 min and then examined under a light microscope by experienced laboratory technicians. Eggs of *S. mansoni*, hookworm, *A. lumbricoides* and *T. trichiura* were counted and recorded separately. For quality control, a random sample of 10% of the slides was re-examined the same day by a senior technician and discrepancies were discussed.

Data management and statistical analysis

Data were double-entered and cross-checked using the EpiData software version 3.1 of (EpiData Association; Odense, Denmark). Statistical analysis was performed in STATA version 9 (Stata Corporation; College Station, TX, USA) and in WinBUGS version 1.4.1 (Imperial College and Medical Research Council; London, UK). Maps and shortest straight-line distances from houses to the Kô River were obtained in ArcMap™ version 9.0 (Environmental Systems Research Institute; Redlands, CA, USA).

Study participants with complete parasitological data (i.e. ≥ 1 Kato-Katz thick smear plus SAF reading) and questionnaire data were included in the final analysis. Age was grouped into five classes: (i) < 10, (ii) 10-14, (iii) 15-24, (iv) 25-39, and (v) ≥ 40 years. An infection with *S. mansoni* or hookworm was defined as the presence of at least one egg either in the Kato-Katz thick smear or the SAF-conserved stool sample. Intestinal protozoan infections were defined by the presence of intestinal protozoa in the SAF reading. For participants with two Kato-Katz thick smears, the arithmetic mean egg count was calculated. *Schistosoma mansoni* infection intensity was classified as follows: light [1-99 eggs per gram of stool (epg)], moderate (100-399 epg), and heavy (≥ 400 epg). For hookworm infections, intensities were grouped as follows: light (1-1999 epg), moderate (2000-3999 epg), and heavy (≥ 4000 epg) (WHO 2002).

The socio-economic status of a household was derived by principal component (PC) analysis (PCA), using selected housing characteristics (e.g. type of wall) and household assets owned (e.g. bicycle). Wealth quintiles were derived from the first PC according to a widely used methodology (Filmer & Pritchett 2001; Gwatkin *et al.* 2000), readily adapted to the local context (Raso *et al.* 2006). Pearson's χ^2, Fisher's exact test, and Wilcoxon signed rank test were used, as appropriate, to compare proportions or medians between groups.

Logistic regression models were fitted to investigate risk factors for an infection with *S. mansoni* or hookworm. Interactions between age, socio-economic status, education and agricultural zone were examined using the likelihood ratio test (LRT). Explanatory variables were entered in the Bayesian spatial and non-spatial multiple regression models in case they were significant at a 15% significance level. Household-specific random effects with an exchangeable correlation structure were introduced to take into account the between-household variation (σ_1^2). Likewise, random effects related to the location of the household were employed to model geographical correlation. The spatial correlation was assumed to be an exponential function of the distance, i.e. $\sigma_2^2 \exp(-\rho d_{kl})$, including the shortest straight-line distance between households k and l (d_{kl}), the geographical variability known as sill (σ_2^2) and a smoothing parameter that controls the rate of correlation decay with distance (ρ). The minimum distance is represented by $3/\rho$ in meters at which spatial correlation between house locations is below 5% and is known as the range of geographical dependency. We fitted two different multiple logistic regression models for *S. mansoni* and hookworm infection prevalence. While the first model did not take into account any random effects, the second model considered between-household variation. Whilst gamma prior distributions were used for σ_1^2 and σ_2^2, a uniform prior distribution was employed for ρ. The model parameters were fitted applying Markov chain Monte Carlo simulation (Gelfand & Smith

1990). As a goodness of fit measure, we used the deviance information criterion (DIC) (Spiegelhalter *et al.* 2002). The model with the smallest DIC was considered the best fitting one. Further details on model specifications have been presented elsewhere (Matthys *et al.* 2006b).

Ethical considerations and treatment

Institutional approval of the study protocol was granted by the Swiss Tropical Institute (Basel, Switzerland) and the Centre Suisse de Recherches Scientifiques (Abidjan, Côte d'Ivoire). The study received ethical clearance by the Ministry of Public Health in Côte d'Ivoire.

Study participants infected with soil-transmitted helminths were treated with a single 400 mg oral dose of albendazole and participants with a *S. mansoni* infection were given a single 40 mg/kg oral dose of praziquantel, adhering to WHO guidelines (WHO 2002).

7.4 Results

Study compliance and socio-demographic characteristics

Overall, 1000 individuals from 159 households participated in our cross-sectional surveys. However, 124 individuals had no or incomplete questionnaire data, and 160 people were absent during our parasitological survey or provided insufficient amounts of stool to prepare two Kato-Katz thick smears. The final study cohort therefore consisted of 716 people from 134 households (586 individuals from 113 farming households and 130 individuals from 21 non-farming households. Sex and age distributions were similar for farming and non-farming households. Among these 716 individuals, we were able to prepare an additional SAF-conserved stool sample for examination of intestinal protozoa (510 individuals from farming and 90 in non-farming households).

The demographic and socio-economic profiles of the farming households have been described before (Matthys *et al.* 2006b). Briefly, two-thirds of the household heads were illiterate, and very few received specific agricultural training. The socio-economic status of the farmers in the different agricultural zones was similar. Half of the households had their own latrines (with a slab made of cement or terra soil), and one-third of the households shared a latrine with their neighbours. The remaining households (17%) had no latrines. The majority of households were inhabited by less than 10 people, but in one out of 20 households over 20 people were registered.

Parasitic infections in farming and non-farming households

The results from the cross-sectional parasitological survey are summarized in Table 1, stratified by farming and non-farming households. The overall infection prevalence of *S. mansoni* and hookworm was 50.1% and 22.9%, respectively. The prevalence of hookworm infections in farming households was significantly higher than that in non-farming households (24.7% *versus* 14.6%; odds ratio (OR) = 0.52 for non-farming households, 95% confidence interval (CI) = 0.31-0.88). Infections with *T. trichiura* were found in 3.4% and *A. lumbricoides* in 1.1% of the participants.

Entamoeba coli (prevalence 53.3%) and *Blastocystis hominis* (37.5%) were the most common apathogenic intestinal protozoa. We found an overall prevalence of *Entamoeba histolytica/Entamoeba dispar* of 18.2%, with a three-fold higher prevalence observed in farming compared to non-farming households, accounting for a highly significant difference (OR = 0.28 for non-farming households, 95% CI = 0.12-0.66). Whilst the prevalence of *Giardia duodenalis* in farming households was 6.3%, not a single infection was detected in non-farming households, resulting in a highly significant difference (Fisher's exact text, P = 0.005).

Concomitant infections with two or more intestinal parasites were observed in 69.6% of the individuals from farming households compared to 55.6% from non-farming households. Absence of intestinal parasites was noted in 13.1% of the individuals from farming families compared to 20.0% from non-farming families (χ^2 = 6.94, degree of freedom (d.f.) = 2, P = 0.031).

***Schistosoma mansoni* and hookworm data**

Table 2 summarizes the prevalence of *S. mansoni* and hookworm infections among individuals from farming and non-farming households, stratified by sex, age, socio-economic status, education level and agricultural zone. In farming households, males had a significantly higher *S. mansoni* infection prevalence than females (58.8% *vs.* 44.9%; χ^2 = 11.30, d.f. = 1, P = 0.001), whereas no significant sex difference was found in non-farming households. In both farming and non-farming households, an infection with *S. mansoni* was significantly associated with age, with a peak in the prevalence found in 15-24-year-olds.

Table 7-1 Number (%) of individuals infected with *Schistosoma mansoni*, soil-transmitted helminths and intestinal protozoa, stratified by farming and non-farming households in the town of Man, western Côte d'Ivoire

Parasite	Overall	Farming households	Non-farming households	OR[a]	95% CI	*P*-value[b]
	[n = 716]	[n = 586]	[n = 130]			
Schistosoma mansoni	359 (50.1)	301 (51.4)	58 (44.6)	0.76	0.52, 1.12	0.164
Soil-transmitted helminths						
Hookworm	164 (22.9)	145 (24.7)	19 (14.6)	0.52	0.31, 0.88	0.010
Trichuris trichiura	24 (3.4)	19 (3.2)	5 (3.8)	1.19	0.44, 3.26	0.734
Ascaris lumbricoides	8 (1.1)	7 (1.2)	1 (0.8)	0.64	0.08, 5.26	0.662
Intestinal protozoa[c]	(n = 600)	(n = 510)	(n = 90)			
Entamoeba coli	320 (53.3)	278 (54.5)	42 (46.7)	0.73	0.47, 1.14	0.170
Blastocystis hominis	225 (37.5)	188 (36.9)	37 (41.1)	1.20	0.75, 1.89	0.445
Endolimax nana	124 (20.7)	113 (22.2)	11(12.2)	0.49	0.25, 0.95	0.024
Entaemoeba histolytica/E. dispar	109 (18.2)	103 (20.2)	6 (6.7)	0.28	0.12, 0.66	0.001
Iodamoeba buetschlii	101 (16.8)	90 (17.6)	11 (12.2)	0.65	0.33, 1.27	0.190
Chilomastix mesnili	50 (8.3)	45 (8.8)	5 (5.6)	0.61	0.23, 1.28	0.278
Entamoeba hartmanni	37 (6.2)	34 (6.7)	3 (3.3)	0.48	0.15, 1.61	0.192
Giardia duodenalis	32 (5.3)	32 (6.3)	0			

[a] OR = crude odds ratio (OR = 1.00 for farming households)

[b] *P*-value based on likelihood ratio test

[c] The prevalence of intestinal protozoan infections is based on the SAF-conserved stool specimens examined by an ether-concentration method

In farming families there was a significant association with *S. mansoni* infection and education attainment; the prevalence of *S. mansoni* infection among college and high school attendants was 38.9% whereas 56.6% of the people not attending school were infected (χ^2 = 9.76, d.f. = 2, P = 0.008). The observed prevalence of *S. mansoni* did not differ significantly between the six agricultural zones, neither for farming nor for non-farming household members.

With regard to hookworm infections, males in farming households had a higher prevalence than females, but the difference was not statistically significant (28.3% *vs.* 21.7%; χ^2 = 3.46, d.f. = 1, P = 0.063). Prevalence of infection showed a highly significant age-relationship in farming households with highest prevalences (31.1-32.2%) found in the three age groups 10-14, 15-24 and 25-39 years (χ^2 = 26.10, d.f. = 5, P < 0.001). In contrast to *S. mansoni*, no significant association was found between hookworm infections and education attainment, but hookworm infection prevalence showed significant spatial heterogeneity between agricultural zones. The highest prevalence both in farming and non-farming households was observed in zone 5 (35.3% in farming households and 32.3% in non-farming households).

Spatial distribution of *Schistosoma mansoni* and hookworm infection among farming households

Figure 1 shows the micro-spatial distribution of *S. mansoni* and hookworm mono-infections and co-infections for individuals from farming households. *Schistosoma mansoni* mono-infections were elevated in zones 1, 6 and 7, located in the western part of the study area. The highest levels of hookworm mono-infections were found in zones 4 and 5, located in the eastern part of the study area. The prevalence of *S. mansoni*-hookworm co-infections ranged from 8.2% (zone 6) to 26.5% (zone 3).

***Schistosoma mansoni* and hookworm infection intensities**

S. mansoni infection intensities were significantly different between farming and non-farming households (χ^2 = 10.05, d.f. = 2, P = 0.007). Heavy *S. mansoni* infections, defined as ≥ 400 epg, were found in 24.1% of the individuals from farming households, compared to only 5.4% in non-farming households. With regard to hookworm infection intensities, 11.3% of the study participants from farming households had moderate-to-heavy infections (defined as ≥ 2000 epg), compared to 5.3% individuals from non-farming households.

Table 7-2 Infection prevalence of *S. mansoni* and hookworm among individuals from farming and non-farming households, stratified by sex, age, socio-economic status, education level and agricultural zone

Parameter	Farming households (n = 586)					Non-farming households (n = 130)				
	Total	*S. mansoni*		Hookworm		Total	*S. mansoni*		Hookworm	
		No. (%)	*P*-value[a]	No. (%)	*P*-value[a]		No. (%)	*P*-value[a]	No. (%)	*P*-value[a]
Sex										
Male	272	160 (58.8)		77 (28.3)		53	24 (45.3)		6 (11.3)	
Female	314	141 (44.9)	0.001	68 (21.7)	0.063	77	34 (42.2)	0.899	13 (16.9)	0.378
Age (years)										
< 10	147	48 (32.7)		14 (9.5)		34	6 (17.7)		4 (11.8)	
10-14	93	59 (63.4)		29 (31.2)		22	10 (45.5)		3 (13.6)	
15-24	121	80 (66.1)		39 (32.2)		28	18 (64.3)		9 (32.1)	
25-39	76	45 (59.2)		24 (31.6)		25	16 (64.0)		1 (4.0)	
≥ 40	149	69 (46.3)	< 0.001	39 (26.2)	< 0.001	21	8 (38.1)	0.001	2 (9.5)	0.067[b]
Socio-economic status										
Poorest	145	80 (55.2)		39 (26.9)		0	0		0	
Very poor	144	83 (57.6)		30 (20.8)		3	2 (66.7)		0	
Poor	99	51 (51.5)		28 (28.3)		40	17 (42.5)		5 (12.5)	
Less poor	96	43 (44.8)		17 (17.7)		46	21 (45.7)		4 (8.7)	
Least poor	102	44 (43.1)	0.110	31 (30.4)	0.164	41	18 (43.9)	0.896[b]	10 (24.4)	0.213[b]
Education level										
No school	318	180 (56.6)		77 (24.2)		56	25 (44.6)		8 (14.3)	
Primary school	178	86 (48.3)		53 (29.8)		50	23 (46.0)		5 (10.0)	
College/high school	90	35 (38.9)	0.008	15 (16.7)	0.060	24	10 (41.7)	0.940	6 (25.0)	0.240[b]
Agricultural zone										
1	55	28 (50.9)		8 (14.6)		18	8 (44.4)		3 (16.7)	
3	68	40 (58.8)		22 (32.4)		0				
4	66	27 (40.9)		21 (31.8)		34	14 (41.2)		2 (5.9)	
5	133	65 (48.9)		47 (35.3)		31	17 (54.8)		10 (32.3)	
6	182	93 (51.1)		28 (15.4)		29	10 (34.5)		2 (6.9)	
7	82	48 (58.5)	0.266	19 (23.2)	< 0.001	18	9 (50.0)	0.576	2 (11.1)	0.031[b]

[a] *P*-value based on Pearson's chi-square-test, [b] *P*-value based on Fisher's exact test

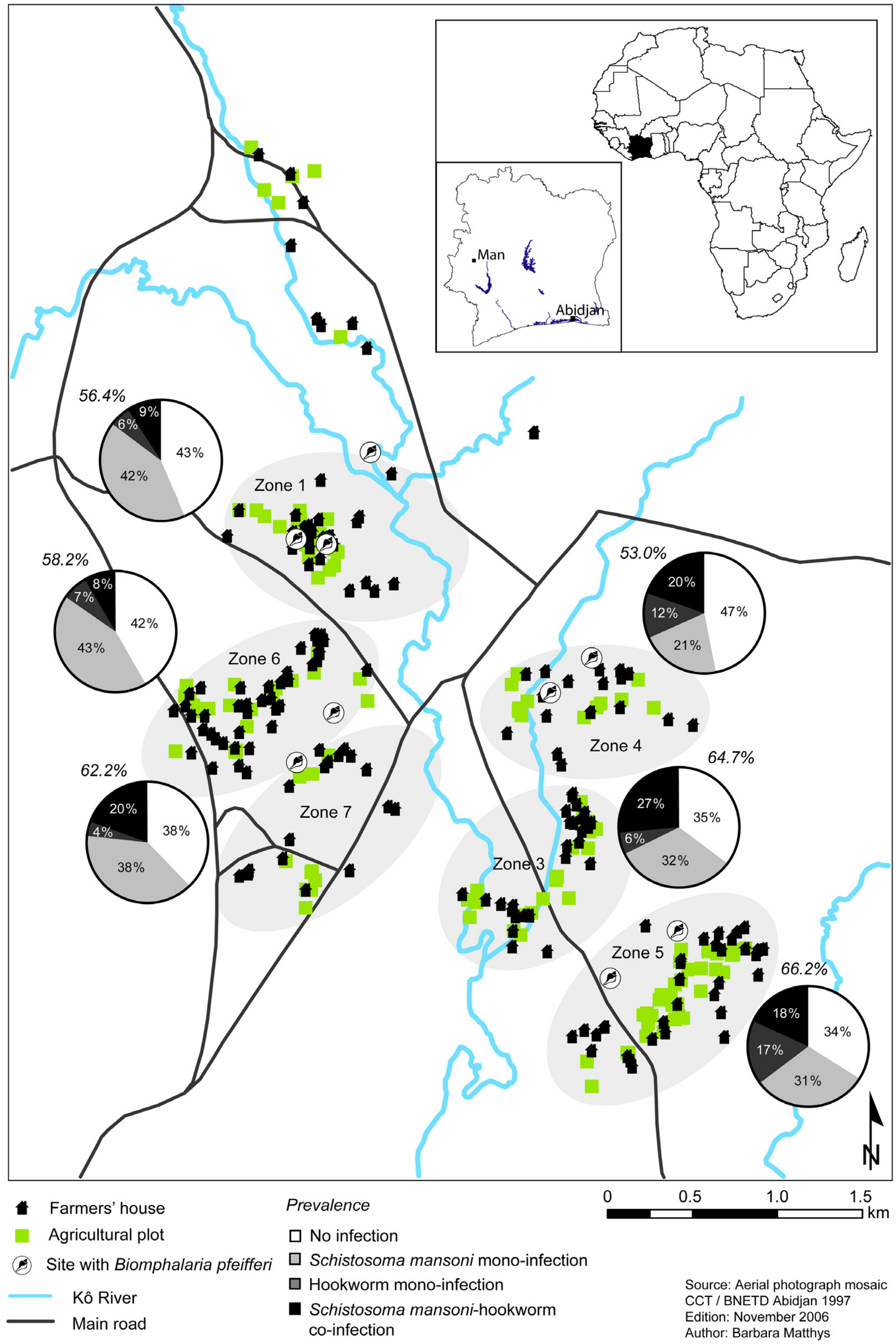


Figure 7.1 Spatial distribution of *Schistosoma mansoni* and hookworm mono-infection and co-infection prevalence among individuals from farming households, stratified by agricultural zone, in the town of Man, western Côte d'Ivoire, June 2005

Household clustering of *Schistosoma mansoni* and hookworm infection

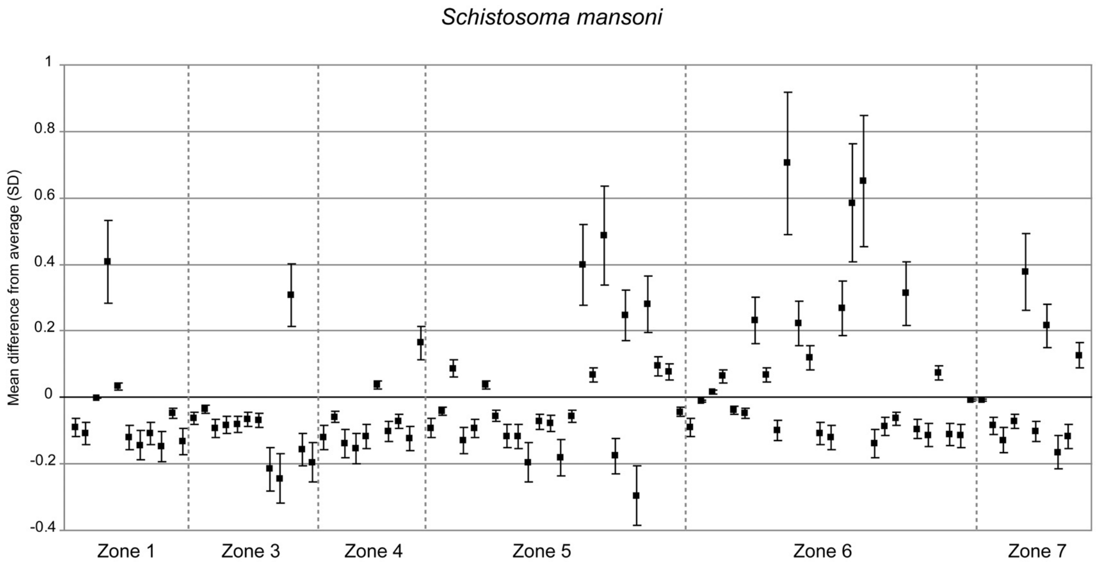
Figure 2 shows household-clustered *S. mansoni* and hookworm infections from 94 and 59 farming households, respectively, with at least one household member infected. The results are further stratified by agricultural zone. After calculating the arithmetic mean (according to Brooker and colleagues (2006b)), egg counts of *S. mansoni* and hookworm for the respective sex and age-class, the standard deviation (SD) for each individual was computed from this mean. The data were averaged by household, and standardized with a mean of 0 and a SD of 1 (Behnke *et al.* 2000). The average level of infection is denoted by the horizontal zero line. *Schistosoma mansoni* and hookworm infections showed pronounced aggregation in a few households. Zone 6 showed the highest averaged *S. mansoni* egg counts per family. Meanwhile, the averaged hookworm infections were below the mean in this zone.

Risk factors for *Schistosoma mansoni* and hookworm infections

Demographic, socio-economic and farming-related risk factors for an infection with *S. mansoni* and hookworm are summarized in Tables 3 and 4. Key findings from the multivariate spatial random effects models are highlighted.

The risk of a *S. mansoni* infection was age and sex-related. Males were at a higher risk of a *S. mansoni* infection than females, as were individuals aged 10-39 years when compared to children below the age of 10 years. The socio-economic status was not significantly associated with a *S. mansoni* infection. A higher education level of the household head was a protective factor (OR = 0.37, 95% Bayesian credible interval (BCI) = 0.19-0.63 for household heads attending college/high school).

Family members living in large households (> 20 persons) were more likely to be infected with *S. mansoni* than members from households with ≤ 5 persons (OR = 2.56, 95% BCI = 1.07-5.23). Household members residing at least 750 m away from the Kô River were at a lower risk of a *S. mansoni* infection than those living in close proximity (OR = 0.61, 95% BCI = 0.37-0.93). Water contact related risk factors were bathing/swimming in the Kô River (OR = 3.16, 95% BCI = 1.42-6.25), fishing with a net (OR = 2.35, 95% BCI = 1.30-3.93) and use of water from irrigation wells and ponds (OR = 2.50, 95% BCI = 1.60-3.76).



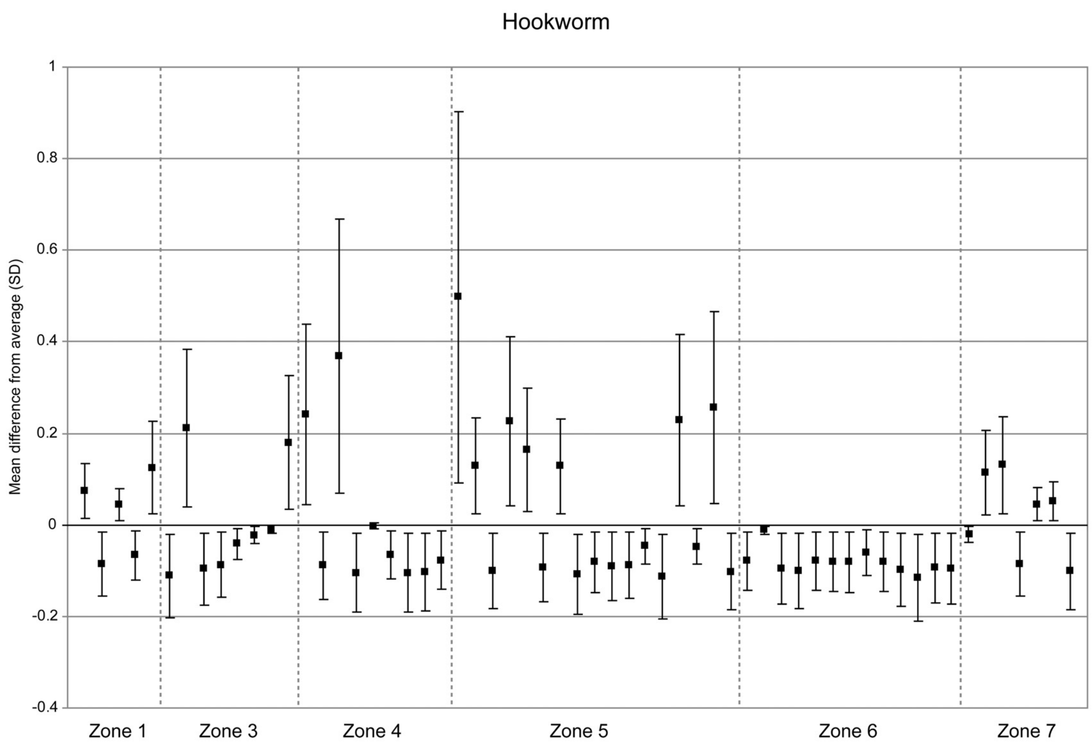


Figure 7.2 Household clustering of *Schistosoma mansoni* and hookworm infection from six agricultural zones in the town of Man, western Côte d'Ivoire, June 2005

Table 7-3 Results of bivariate, non-random model and spatially-explicit random effects multivariate logistic regression model. Outcome: *Schistosoma mansoni* infection; explanatory variables: demographic and education, socio-economic, household characteristics and agricultural parameters. Medians were used to summarize the posterior distribution of the parameters of the Bayesian model

Explanatory variables	Bivariate model			Bayesian multivariate model[a]	
	OR	95% CI	*P*-value[b]	OR	95% BCI
Demography					
Sex					
Male	1.00			1.00	
Female	0.57	0.41, 0.79	0.001	0.46	0.29, 0.67
Age (years)					
< 10	1.00			1.00	
10-14	3.58	2.08, 6.17		4.77	2.34, 8.81
15-24	4.02	2.42, 6.70		5.81	2.94, 10.52
25-39	2.99	1.69, 5.31		5.70	2.61, 11.04
≥ 40	1.78	1.11, 2.85	< 0.001	2.32	1.21, 4.08
Socio-economic status					
Poorest	1.00			1.00	
Very poor	1.11	0.69, 1.76		1.94	0.97, 3.52
Poor	0.86	0.52, 1.44		1.07	0.50, 2.01
Less poor	0.66	0.39, 1.11		1.24	0.57, 2.39
Least poor	0.62	0.37, 1.03	0.109	0.93	0.42, 1.78
Education level					
No school	1.00			1.00	
Primary school	0.72	0.50, 1.04		0.69	0.40, 1.10
College/high school	0.49	0.30, 0.79	0.007	0.37	0.19, 0.63
Number of persons living in household					
1-5	1.00			1.00	
6-10	1.22	0.74, 2.03		1.24	0.62, 2.23
11-20	0.94	0.55, 1.60		1.19	0.57, 2.22
> 20	1.87	0.97, 3.26	0.083	2.56	1.07, 5.23
Toilet disposal					
Latrine used by only one household	1.00			1.00	
Shared latrine within household yard	1.26	0.87, 1.80		1.69	1.02, 2.65
No toilet	1.96	1.24, 3.10	0.014	1.96	0.96, 3.60
Distance to river					
≤ 750 m	1.00			1.00	
> 750 m	0.57	0.40, 0.82	0.002	0.61	0.37, 0.93

Bathing/swimming in Kô River	1.64	0.97, 2.78	0.062	3.16	1.42, 6.25
Fishing with a net	1.64	1.09, 2.46	0.016	2.35	1.30, 3.93
Farming-related risk factors					
Contact with water from irrigation well or pond	1.74	1.25, 2.42	< 0.001	2.50	1.60, 3.76
Cultivated crop type					
Rain-fed rice[c]	1.00	0.69, 1.36	0.995		
Irrigated rice[c]	1.24	0.86, 1.78	0.251		
Market garden vegetables	0.58	0.42, 0.82	0.002	0.76	0.45, 1.20
Rain-fed food crops	1.67	1.19, 2.33	0.003	1.45	0.93, 2.16
σ_1^2 (non-spatial variation)				0.12	0.03, 0.40
σ_2^2 (spatial variation)				0.04	0.00, 0.25
ρ (smoothing parameter)				0.54	0.08, 0.98
Deviance information criterion					730.0

BCI = Bayesian credible interval; [a] Spatially-explicit model with household and location-specific random effects; [b] *P*-value based on likelihood ratio test (LRT); [c] Not included in the multivariate model

A hookworm infection was age-related, but sex showed only borderline significance. Other risk factors for a hookworm infection included low socio-economic status (OR = 0.25, 95% BCI = 0.08-0.59 for 'less poor'), living in agricultural zone 4 (OR = 6.69, 95% BCI = 1.65-19.05) or zone (OR = 6.54, 95% BCI = 1.97-16.96) and the use of domestic water from a well (OR = 2.32, 95% BCI = 1.24-4.05).

Spatial correlation of *Schistosoma mansoni* and hookworm infections

The results of the multivariate spatial random-effects regression models (Tables 3 and 4) indicate that the spatial autocorrelation of *S. mansoni* and hookworm infections were negligible. In fact, the minimum distance at which the spatial correlation between houses dropped below 5% was 5.6 m in the case of *S. mansoni* and 5.4 m in the case of hookworm.

Table 7-4 Results of bivariate, non-random model and spatially-explicit random effects multivariate logistic regression model. Outcome: hookworm infection; explanatory variables: demographic and education, socio-economic, household characteristics and agricultural parameters. Medians were used to summarize the posterior distribution of the parameters of the Bayesian model

Explanatory variables	Bivariate model			Bayesian multivariate model[a]	
	OR	95% CI	*P*-value[b]	OR	95% BCI
Demography					
Sex					
Male	1.00			1.00	
Female	0.70	0.48, 1.02	0.063	0.64	0.38, 1.01
Age (years)					
< 10	1.00			1.00	
10-14	4.30	2.13, 8.70		6.05	2.31, 13.41
15-24	4.52	2.31, 8.83		7.30	2.96, 15.74
25-39	4.38	2.11, 9.13		6.48	2.38, 14.73
≥ 40	3.37	1.74, 6.52	< 0.001	5.60	2.31, 11.91
Socio-economic status					
Poorest	1.00			1.00	
Very poor	0.72	0.41, 1.23		0.63	0.27, 1.27
Poor	1.07	0.61, 1.90		0.62	0.21, 1.40
Less poor	0.58	0.31, 1.11		0.25	0.08, 0.59
Least poor	1.19	0.68, 2.08	0.156	0.57	0.20, 1.28
Number of persons living in the household					
1-5	1.00			1.00	
6-10	0.93	0.51, 1.69		1.39	0.54, 3.03
11-20	0.94	0.51, 1.76		1.04	0.36, 2.42
> 20	1.73	0.89, 3.38	0.106	2.61	0.86, 6.19
Toilet disposal					
Latrine used by only one household	1.00			1.00	
Shared latrine within neighbouring household	1.06	0.69, 1.62		0.56	0.29, 0.98
No toilet	1.35	0.82, 2.23	0.496	1.23	0.51, 2.53
Agricultural zone					
1 (mixed crops)	1.00			1.00	
3 (mixed crops)	2.81	1.14, 6.95		3.07	0.81, 8.42
4 (traditional smallholder plot)	2.74	1.10, 6.82		6.69	1.65, 19.05
5 (large rice perimeter)	3.21	1.40, 7.36		6.54	1.97, 16.96
6 (traditional smallholder plot)	1.07	0.46, 2.50		1.55	0.38, 4.39

7 (traditional smallholder plot plus large rice perimeter)	1.77	0.71, 4.39	<0.001	1.79	0.38, 4.39
Private well in yard	1.60	1.03, 2.47	0.032	2.32	1.24, 4.05
Washing clothes in River Kô	1.58	1.06, 2.34	0.024	1.61	0.91, 2.67
Cultivated crop type					
Rain-fed rice	0.53	0.33, 0.186	0.001	0.52	0.21, 1.07
Irrigated rice	0.84	0.56, 1.27	0.405	1.87	0.89, 3.52
Vegetables	1.60	1.07, 2.40	0.019	1.73	0.84, 3.19
Rain-fed food crops[c]	0.89	0.61, 1.32	0.570		
σ_1^2 (non-spatial variation)				0.23	0.04, 0.99
σ_2^2 (spatial variation)				0.54	0.20, 1.36
ρ (smoothing parameter)				0.56	0.09, 0.98
Deviance information criterion					596.8

BCI = Bayesian credible interval; [a] Spatially-explicit model with household and location-specific random effects; [b] *P*-value based on likelihood ratio test (LRT); [c] Not included into the multivariate model

7.5 Discussion

We investigated risk factors for *S. mansoni* and hookworm infections, including micro-spatial heterogeneity, in farming and non-farming households in a medium-sized town of Côte d'Ivoire. Both descriptive and Bayesian spatial statistics were employed. Our findings confirm that the distribution of *S. mansoni* and hookworm is highly focal also in this urban setting with irrigated rice cultivation zones (Fenwick *et al.* 2006; Raso *et al.* 2006). Moreover, infection prevalences of both parasites in farming communities were related to agricultural activities.

Four aspects pertaining to urban agriculture are particularly noteworthy. First, highest levels of household-aggregated *S. mansoni* infections were found in a zone of smallholder irrigated rice plots (zone 6). Second, agricultural risk factors for a *S. mansoni* infection included the use of water from irrigation wells and ponds. These two observations are underscored by the discovery of *B. pfeifferi* from irrigation wells, canals and ponds in agricultural zones 1, 4, 5, 6 and 7 and human water contact sites in the Kô River in October 2004 and April 2005. Laboratory investigations revealed that the snails were shedding *S. mansoni* cercariae (sites where *B. pfeifferi* were collected are marked on Figure 1). A previous study already established a link between *S. mansoni* infection and irrigated rice cropping systems in Côte d'Ivoire (Yapi *et al.* 2005). Household-aggregated *S. mansoni* infections related to agricultural water contact have also been reported from Brazil (Bethony *et al.* 2004). The observed differences in *S. mansoni* infections among males and females in farming households are probably associated with gender-specific water contact patterns, already documented from irrigated river valleys in Morocco (Watts *et al.* 1998).

Third, households located in agricultural zones of smallholder irrigated rice cultivation and a large irrigated rice perimeter (zones 4 and 5) were at an elevated risk of hookworm infection. Fourth, high *S. mansoni*-hookworm co-infections were clustered in a zone of a large rice perimeter (zone 5). Zones 3, 4 and 5 are located east of the Kô River and the clustering of hookworm and *S. mansoni*-hookworm co-infections in these zones cannot be explained by spatial disparities of the socio-economic status of farming communities or by the cultivated crop types. While the eastern part of the town of Man is a plain, the western part is hilly, which probably results in marked differences in soil types. Variations in clay content and soil structure can play an important role in providing suitable habitats for hookworm eggs and larvae, as recently observed in a study in South Africa (Saathoff *et al.* 2005). Spatial clustering of hookworm infections within a few hundred meters has also been observed in a village and small settlement some 20 km east of the town of Man (Utzinger *et al.* 2003) and in an urban setting of Brazil (Brooker *et al.* 2006a).

A methodological shortcoming of our study was that only one stool specimen was collected from each participant. It is widely acknowledged that there is important day-to-day and intra-stool variation of *S. mansoni* and hookworm egg output (Booth *et al.* 2003; de Vlas & Gryseels 1992; Engels *et al.* 1997; Utzinger *et al.* 2001). To enhance the diagnostic sensitivity, we prepared two Kato-Katz thick smears from each stool specimen, and employed an ether-concentration method and considered the combined diagnostic results in our final analyses.

Close proximity to the Kô River was identified as a significant risk factor for a *S. mansoni* infection. Domestic, agricultural, recreational and other activities were carried out at the riverside by people living close-by. Thus, households located a few hundred metres from the Kô River are at a higher risk of *S. mansoni* than households situated further away as frequency of water contact depends on distance to infected sources of water (Brooker *et al.* 2001). Recent studies focussing at micro-geographical units of analysis, carried out in Kenya, showed that prevalence and intensity of *S. mansoni* and soil-transmitted helminth infections were distance-dependent from lakes and permanent water bodies (Booth *et al.* 2004; Clennon *et al.* 2004; Handzel *et al.* 2003).

The significantly higher hookworm prevalence in farming households than in non-farming households, particularly among males, might be associated with the work-related presence in green areas that provide at the same time hiding places for open defecation.

Although wearing of footwear was not systematically assessed in our study, we observed that farmers on agricultural plots rarely wore boots, closed shoes or sandals. Wearing shoes was reported as "uncomfortable" when working in the field because of the wet soils and penetrating water. Footwear appeared as a protective factor against soil-transmitted helminth infections in tea-growing communities in India (Traub *et al.* 2004), but had no effect on hookworm infections in another study from Mali (Behnke *et al.* 2000).

The prevalence of hookworm was considerably lower in the current population sample when compared to a household-based study conducted in a village 30 km east of Man in 2002 (Raso *et al.* 2004). Other school-based and community-wide investigations revealed no significant rural-urban differences of hookworm prevalence (Brooker *et al.* 2006b; Sinuon *et al.* 2003), which is in contrast to our findings. However, differences in hookworm patterns were found between rural and peri-urban agricultural settings, as well as in non-agricultural urban settings of Vietnam (van der Hoek *et al.* 2003), with highest prevalence occurring in peri-urban settings with intensive vegetable farming. These observations, together with the fact that the socio-economic status did not differ between farming and non-farming communities in our study area, support agriculture-related hookworm profiles in farming communities.

Risk factors for a *S. mansoni* infection were governed by living conditions, including high numbers of household members and sharing a latrine with neighbours. Household crowding has been reported to be associated with *S. mansoni* (Gazzinelli *et al.* 2006) and with hookworm infection (Curtale *et al.* 1998; Olsen *et al.* 2001; Traub *et al.* 2004). We assume that "shared latrines" are part of domestic activities associated with water usage and storage that are not necessarily limited to one household (Cairncross *et al.* 1996), and resulting in shared infective sites (Bethony *et al.* 2001). The use of water from domestic wells was another risk factor for hookworm infection. Moist shaded soil around wells provides suitable living conditions for infective hookworm larvae. Differences in defecation habits by adults and children result in distinct hookworm transmission patterns (Chan *et al.* 1997). In an investigation from Thailand, soil samples taken in family yards around foot-washing zones, under trees and near latrines were highly contaminated with soil-transmitted helminths (Chongsuvivatwong *et al.* 1999). In the present study, low education attainment was a risk factor for *S. mansoni*, and low socio-economic status for hookworm infection. Note that people's socio-economic status was assessed by a household-based asset approach. In our previous work done in surrounding villages in the Man area we used the same household-based asset approach which proved to be useful to understand schoolchildren's infection status with *S. mansoni*, hookworm, co-infection and multiparasitism (Raso *et al.* 2005).

The extremely low spatial correlation of both parasites investigated (i.e. 5-6 m) might be explained by shared transmission sites and common exposure among neighbouring households. With regard to *S. mansoni*, contact with irrigation wells and ponds was identified as a risk factor. Given the close proximity of irrigation wells and ponds in rice paddies and market gardens to farmers' houses, shared transmission is likely to occur. With regard to hookworm infection, it is conceivable that shared transmission sites were private wells in house yards. A comparable study carried out in a small urban area in Brazil, also using Bayesian inference, lends support to our suggestions of shared transmission sites at the peri-domestic area for hookworm infection and proximity to infested water bodies for *S. mansoni* infection (Brooker *et al.* 2006a). A study carried out in a rural Brazilian setting found spatial correlations over a larger distance for both parasites (Brooker *et al.* 2006a). We speculate that in densely populated urban settings with small-scale land use patterns, transmission sites are more clustered when compared to rural settings where more open space is available. Findings from a study at a medium spatial scale (56 rural schools scattered over a 40 x 60 km surface) revealed a quasi absent spatial correlation (~2 km) of hookworm infections between villages (Raso *et al.* 2006). Another investigation at a relatively large scale (i.e. 530 x 670km) from Tanzania found a spatial correlation of 3.4 km for *S. mansoni* infections at village locations along lake shores and perennial water bodies (Clements *et al.* 2006). The prediction of high-risk areas for targeting control interventions is usually carried out at large spatial scales, and hence takes into account only the aggregated village rather than the household level. This issue prevents direct comparison with small-scale studies carried out at the household level. In future investigations at large-scale, it would be interesting to explore spatial effects at the household level.

Prediction maps based on the Bayesian regression models were tested for the prevalence of *S. mansoni* infection in Man (data not shown). Emphasis was placed on girls, aged 10-14 years, as we assumed that this group was minimally involved in agricultural activities and thus, contact with infested transmission sites was probably reduced to the Kô River. Lower infection prevalences were predicted for zones ≥ 700 m away from the Kô River. A limitation of our prediction is that it was based on a single environmental explanatory variable, i.e. distance to the Kô River. We suggest that human behaviour-related factors are equally or even more important to explain *S. mansoni* infections than environmental factors at a small-scale.

This outcome needs to be taken into consideration in further spatial investigations that focus on the micro-geographical distribution of *S. mansoni* and employ Bayesian spatial statistics.

In conclusion, the present study emphasises micro-spatial heterogeneity of *S. mansoni* and hookworm infections in farming communities of a typical medium-sized town of Côte d'Ivoire. Contextual determinants include agricultural, behavioural, demographic, environmental and socio-economic factors. Our spatial Bayesian modelling approach at this scale was limited to identify risk factors, which can be explained by individual- and household-based behavioural factors that are more important at this scale than environmental parameters. Future studies should investigate whether Bayesian spatial statistics can explain clustering of human parasitic infections at such small scales in different parts of the world. As chemotherapy-based control programmes of schistosomiasis and soil-transmitted helminthiasis target large communities rather than specific households, more work remains to be carried out to further our understanding of infection patterns among special high-risk groups, such as farming communities. Chemotherapy should go hand-in-hand with sound health education, and active participation of urban farmers for prevention and control of helminth infections.

7.6 Acknowledgements

We thank all families for active participation. We acknowledge political and religious leaders, school directors and community youth associations for placing rooms and other infrastructures at our disposal during the cross-sectional surveys. We are grateful to D. Doua and his team (S. Tokpa, M. Kpan, C. Gueu Sadia, R. Dion, P. Blé Gosamé, A. Thian Yohan and S. Sadia) of the non-governmental organization ODAFEM in Man for their commitment in this study. We thank M. Koné from the Université de Bouaké and E. Gbede Becket for help with the socio-economic survey. We are grateful to the laboratory technicians (A. Allangba, A. Fondjo and B. Sosthène) and the medical field staff of Man for their excellent work in the field and laboratory. We thank M. Mabaso for statistical support. Comments from two anonymous referees helped in further improving this This investigation received financial support from the National Centre of Competence in Research (NCCR) North-South programme entitled "Research partnerships for mitigating syndromes of global change", individual project no. 4 (IP4), entitled "Health and well-being", the Swiss Development Cooperation (SDC) for support granted to the Centre Suisse de Recherches Scientifiques via a project entitled "Contribution to the process of national reconciliation in Côte d'Ivoire", and the Swiss National Science Foundation (SNF) through a research project to P. Vounatsou and

L. Gosoniu (project no. 3252B0-102136), a fellowship to G. Raso (project no. PBBSB-109011), and a 'SNF-Förderungsprofessur' to J. Utzinger (project no. PP00B--102883).

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8. Discussion

The aim of the present PhD thesis was to further our understanding of the effect of urban agricultural land use patterns and agricultural activities on the transmission of malaria, schistosomiasis, soil-transmitted helminthiasis and intestinal protozoan infections in different urban settings of Côte d'Ivoire. In the following sections, we will discuss the contextual determinants that may govern the predisposition and vulnerability of urban farmers to parasitic diseases. The two urban settings, i.e. the economic capital Abidjan with an estimated population of 3.3 million people (United Nations 2004), and the medium-sized town Man (estimated population in 1998: 115,000), are placed in a broader context, and we consider factors that act at regional, community, household and individual level. Risk factors, perceived illness and examples of local coping strategies are analysed with pointed emphasis on community and household level. The main outcomes of our analysis are summarized, which in turn allows putting forward a set of recommendations for future research as well as prevention and control interventions that are readily adapted to the local eco-epidemiological settings (Chapter 9).

8.1 Contextual determinants

8.1.1 Urban land use regulation and the current socio-political context

Contemporary urban land use patterns are a result of national and municipal regulation policies. Our investigations showed that agricultural land use varies considerably between Abidjan and Man. In the farmer setting, agriculture is not officially recognized by the city authorities, and the tenure status of the producers largely depends on the goodwill of private and public landowners. As a result of the dynamics of infrastructure development, zones of agricultural land use emerge and disappear often at a rapid pace. Scarce vacant land spots along the lagoon shores are mainly cultivated by immigrants for production of high-yield vegetables to be sold on local markets. Informal local farmer community structures with elected delegates in some of the agricultural zones are a response of the producers to strengthen and institutionalise their interests from the municipal authorities. These delegates act as negotiation partners for external stakeholders and represent the backbone of the community organization. To some extent, farmer communities indicate the degree of social coherence and stability in agricultural zones, particularly with regard to land use dynamics. Such structures were absent in areas where infrastructure development progressed fastest and where land pressure was particularly high. We observed health-related social networks among farming households in case of illness.

At present, land pressure in the town of Man is considerably lower when compared to Abidjan and urban agriculture is better tolerated by the city municipality. Land usually belongs to the municipality and tenure is based on customary land rights and regulated by community chiefs and the local authorities. Traditional irrigated rice farming and vegetable production in lowlands and along the Kô River are the predominant agricultural activities. Farming is family- and subsistence-based.

The physical and social structure of neighbourhoods plays an important role for health interventions. The constructed environment of Abidjan is clustered at neighbourhood level, segregating residential, poor settlement, and newly constructed areas. Stakeholders, e.g. farmers and women association groups, which pursue common interests, define community structures. In Man, in contrast, residential and other houses are mixed resulting in a higher homogeneity of the neighbourhoods. Local community structures cover larger spatial entities.

The socio-political crisis of Côte d'Ivoire that reached a peak in September 2002 and has persisted to date showed a considerable impact on the livelihoods of the households and resulting land use patterns in the two study zones. Underlying reasons for the socio-political conflict have been detailed elsewhere (Akindès 2004; Woods 2003). This political instability led to a further deterioration of the insecure residency status of urban farmers in Abidjan. The increased frequency of identity checks including residential status assessment and raids by governmental authority forces and militants, together with growing insecurity in the neighbourhoods, forced an unknown number of household heads to send back their family members to their home countries. As a response to the theft of vegetables, the urban farmers organized themselves and set up guards during night. In turn, however, these moves enhanced exposure of the guards to mosquito bites and the risk of malaria.

We conjecture that marginalized population groups, such as immigrants with insecure permit status, are less likely to consult local public health structures but instead rather consult traditional healers and private health services. In addition, marginalized informal settlements inhabited by immigrants are rarely target areas for public health campaigns. If progress towards the Millennium Development Goals (MDGs), particularly MDG #1 is to be made, there is a need to also focus on these population groups (United Nations 2003; Utzinger & Keiser 2006). It is encouraging to note that local community structures and NGOs are often active in such settings, and they are also the target of health-related programmes initiated by humanitarian organizations, e.g. the National Red Cross (Obrist et al. 2006). Neighbourhood communities build important nodes for the implementation of intervention programmes and the access of target groups to these programmes.

The agricultural activities in the town and region of Man decreased once the region was under the control of the rebel forces. Productivity remained low owing to armed raids in villages and internal conflicts over land. After a progressive stabilization and implementation of agricultural projects by international organizations, agricultural activities increased again and were reinforced (personal remarks by international and local NGOs). The persisting overall insecurity forced the rural population to adopt their own risk management strategies. Those families that remained in the villages laboured small plots only. This strategy allowed them to minimize their crop loss in case they had to suddenly abandon the villages due to attacks. Farming of short-life cycle fast growing crops gained in importance. Resources from long-term cash crops worsened the household's economic situation. Increasing armed aggressions on roads cut the urban-rural mobility, including rural-urban food transfer from relatives in villages, which has been described as a vital network to satisfy food needs of urban dwellers in other African towns (Frayne 2004). Land use in the surroundings of the town of Man was modified during the absence of governmental structures. Mountain flanks were deforested and cultivated in order to ascertain food security. Qualified public health staff abandoned the rebel-held zones, which led to the collapse of the public health services in the region (Betsi et al. 2006). Health care in the town of Man was increasingly run by humanitarian agencies whereas in the region, access to health services became even more difficult than before 2002 when it was already limited for poor families (Raso et al. 2005b). The interruption of the waste disposal service in Man and unsupervised dumping on idle areas within residential zones probably created numerous additional dumps within the residential areas. It is conceivable that these developments resulted in additional negative health effects, for example malnutrition due to decreased food production (Agadjanian & Prata 2003). Quantifying the health impacts of conflicts is a challenging task due to non-functioning health information and civil registration systems (Murray et al. 2002).

8.1.2 Environmental factors

The agricultural zones in Abidjan and Man are all located in close proximity to inhabited areas. Primarily irrigation wells and agricultural trenches provided productive *Anopheles* mosquito breeding sites in market gardens of Abidjan. Highest *P. falciparum* infection prevalences in farming families were observed in large market garden areas surrounded by open green spaces. Irrigation wells and agricultural trenches in market gardens, and flooded and recently transplanted rice paddies were identified as most productive *Anopheles* breeding sites in agricultural zones of Man. The highest malaria prevalence rates in children below the age of 15 years were observed in two zones of mixed crops and a large rice perimeter. These observations might indicate stable conditions for mosquito breeding in these environments during the rainy and dry season. The proximity of houses to large permanent pools and fish ponds was an environmental predictor for *P. falciparum* infection and distance to the Kô River for *S. mansoni* infection.

Observed household waste dumps in the surroundings of the agricultural zones in Abidjan, and human faeces in and around building shells, in bushy sites and at the lagoon shores are likely to play a role in the transmission of soil-transmitted helminthiasis. Since measured prevalences of soil-transmitted helminth infections were comparable in farming and non-farming households, we conclude that agricultural, domestic and public environments provide suitable transmission sites (Cairncross et al. 1996). Waste removal services are irregular even in Abidjan's better-off urban districts, and the lack of connections of latrines to sewers has been reported also in other poor settlements (so called "quartiers précaires") of Abidjan (Kouassi 2004; Obrist et al. 2006).

8.1.3 Socio-economic status and related factors

It is widely acknowledged that the poorest families are disproportionately affected by human parasitic diseases (Bates *et al.* 2004; Victora *et al.* 2003). Related to their socio-economic situation, producers in Abidjan who lost supplementary livelihood opportunities (e.g. as night guardian of buildings) shifted to full-time vegetable production and loaned plots from other producers. Consequently, the economic vulnerability of these households was increased, since the plots became smaller and yields were reduced, and income was mainly derived from a single activity. In addition, the vulnerability of the households might have been amplified by the reported accommodation of relatives who left the instable rural zones and sought shelter in the cities.

The domestic domain of the farming families in Abidjan provided a suitable environment for the proliferation of soil-transmitted helminths through a lack of sanitation facilities, to intestinal protozoa via water and food storage, and to malaria through sub-optimal house constructions, e.g. non-screened windows and open eaves. Housing and sanitation facilities were precarious in almost all families; a large part of the houses were built of wood and plastic drapery that served to repair roofs and walls. One out of six households lacked any kind of sanitation facilities, in the remaining households, latrines were in the yard, but only rarely connected to a sewer. Domestic water was procured mainly from local providers and private wells in the yard yielding water from the lagoon; hence there was a considerable risk of drinking contaminated water. Comparably poor conditions of the domestic sanitary environment have been reported in other poor settlements (Obrist et al. 2006). Houses in Man were primarily built with concrete, and a few with wood and traditional clay ("banco"). Most households had a traditional latrine in their yard. Similarly to Abidjan, one out of six households, however, lacked any kind of latrine. Most of the households had private wells, but a few procured the domestic water from local providers.

The socio-economic status, estimated by a household-asset based approach, was homogeneous in the study population of Abidjan. The number of assets owned was generally lower in Man when compared to Abidjan, possibly explained by house looting in Man during the first months of control by the rebel forces. The most frequently owned assets were a radio and a television in both urban farming communities, but only every fifth household reported to own a bed net. A positive association between the socio-economic status and sleeping under a bed net was reported in a recent study carried out in two Kenyan cities (Macintyre et al. 2002).

Shared core preoccupations of both farming communities were the households' economic situation, the ongoing socio-political conflict and food security. Household- and work-related health problems were significantly more often reported in Man. We assume that the individual perception of "disease" and "health risks" in the studied farming communities was embedded in the context of the households' economic conditions. This is a crucial outcome since "health consciousness" is an important entry point for community participation with regard to the implementation and sustaining health interventions. Farmers in Abidjan seemed to be less aware of intestinal parasites when compared to Man. Possible explanations are that symptoms of such infections are often recognized only after a long duration of infection. However, the farmers were well conscious about health risks related to their working environment as revealed during in-depth interviews. Household waste disposals, open defecation sites near their plots and polluted water were perceived as main health risks. Our findings are in agreement with other poor settlements in Abidjan, where open drains used as dumps (Granado et al. 2006), or the lagoon shore with polluted water and the presence of dumps (Koné et al. 2006) were perceived as a main environmental factor causing malaria. Medicinal plants grown on vegetable plots and used for self-treatment indicated one of various health seeking strategies. Indeed, a broad spectrum of remedies against malaria is used and various strategies are applied by people living in Abidjan

(Granado et al. 2006; Koné et al. 2006). However, a deep understanding of daily health practices, perceptions of health and illness and the role of the household in managing health in a complex and dynamic social and environmental context is required in improving public health in developing countries (Berman *et al.* 1994; Obrist 2006a; 2006b).

8.1.4 Cultural aspects and related practices

The transmission of schistosomiasis and soil-transmitted helminthiasis in urban farming communities was governed at the level of the household by exposure-related behaviour, such as occupational- and gender-related activities, household-related "spatial mobility" and "shared transmission sites". In Abidjan, the household head, which was only periodically assisted by other family members, primarily did vegetable production. This observation probably explains the marked gender- and occupational-related differences of hookworm infection. In Man, all family members were engaged in farming activities, which might explain the higher levels of hookworm, *E. histolytica/E. dispar* and *G. duodenalis* infections in farming compared to non-farming families. The prevalence with *S. mansoni* was higher in males than females, probably because rice cultivation, which is a risk factor for schistosomiasis (Fournet et al. 2004), is generally carried out by men. On the other hand, women primarily do vegetable gardening.

Agricultural practices determined spatio-temporal mobility patterns; periodic overnight stays in farm huts was a risk factor for *P. falciparum* infection in Man. Our study in the village of Zouatta II revealed that water sources on the agricultural plots shared by several households appeared as collective transmission sites for hookworm, and were related to *P. falciparum* infections, indicating permanent mosquito breeding sites near temporary farm huts. Using water from private domestic wells was associated with hookworm infections in Man. In Abidjan, food and water purchased from mobile sellers (so called "vendeurs ambulants") might be one of the infection sources of intestinal protozoa, also reported from a health risk study related to market gardening in Ouagadougou (Cissé 1997). Family-aggregated clustering of schistosomiasis and hookworm infection in irrigated rice production zones of Man was linked to croptype-specific infection sites (i.e. ponds, irrigation wells and canals) for schistosomiasis.

8.1.5 Key findings of the work

- *P. falciparum*, soil-transmitted helminths (and *S. mansoni* in Man) were heterogeneously distributed between the agricultural zones in both urban settings. Living in specific agricultural zones in Man was a risk factor for infections with all parasites and highest concentrations of these parasites were observed in a zone of a large rice perimeter.

- Identified risk factors for *P. falciparum*, *S. mansoni* and hookworm related to farming practices in Man included living near permanent man-made ponds, periodic stays overnight in farm huts (*P. falciparum*), water contact with irrigation wells (*S. mansoni*).

- The most productive *Anopheles* breeding sites in agricultural zones of Man were man-made habitats (i.e. agricultural trenches, irrigation wells and flooded and recently transplanted rice paddies).

- Symptoms due to intestinal parasitic infections were probably underestimated by the farmers in Abidjan because of their latent nature. On the other hand, waste dumps and sites of human defecation in their working environment were perceived as health risks.

- Farmer community structures in some of the zones, and the social network among the farmers represent a "social capital" indicating the degree of stability in a specific agricultural zone with regard to the intensity of pressure on urban land.

8.2 Strengths of the present study and suggestions for research

8.2.1 Research in unstable socio-political regions

From an operational viewpoint, our work has demonstrated that research in the current post-conflict context of Côte d'Ivoire is feasible. This was enabled by a strong institutional set up, i.e. the CSRS in Abidjan, which was founded in 1951 and managed to maintain its activities throughout the entire conflict period, and the strong research partnership between the CSRS, STI, and the Université de Cocody Abidjan. Reflections on these experiences have been presented in a recent workshop together with Stefanie Granado, also doing her PhD thesis at STI and working in Abidjan between 2003 and 2005 (Matthys & Granado 2006). However, the partnership configuration between the researchers, the local research partners and the local population may become a source of conflict if danger is perceived by each actor differently, if some actors are privileged (i.e. when different safety rules are applied for expatriates and local staff), and if responsibilities and leadership in a team during a mission have not been clearly defined. Based on our experiences, we grouped the main safety-strategies within a research partnership in case of a conflict setting into “information”, “communication” and “respect the rules”, as detailed below:

- *Information*. Researchers and team members need to be informed based on all available information sources. Resource persons and institutions also need to be informed about the planned work and specific details of a field mission.
- *Communication*. It is crucial to explain precisely the position of the various people involved and to provide detailed information on planned work (e.g. purpose and procedures of work and collaborating partners) to all important local and national structures and international organizations before the research is started in a given study area. Of crucial importance are also the networking and a regular contact with international organizations (e.g. ICRC, UN peacekeepers) on the spot. These international organizations are indispensable for the security of the international staff and an eventual evacuation. Moreover, confidants (e.g. expatriates from international organizations working in the zone) can be helpful for advising and debriefing.
- *Respect the rules*. Flexibility is required in accepting the limits and pulling back if a situation risks getting out of control, and the handling according to the current situation. Researchers should be aware of their roles and responsibilities for the field team, because they are not considered as neutral by the different working partners and the local population.

Another important issue were our repeated visits of the agricultural zones in Abidjan and Man together with local field assistants before and during the period of actual field work. Applying this strategy, we progressively gained the trust of the farmers and the local population. Qualitative research methods are considered to represent an important methodology when working with local people in conflict settings (McDonnell et al. 2004). Factors that argue for short missions (safety of the field team and financial aspects) and factors arguing for additional days of field work (local networks and trust building) must be balanced carefully.

Epidemiologists are increasingly asked to measure health risks and the state of public health systems in areas of conflict, to provide recommendations regarding risk mitigation, and to propose feasible means for re-establishing health systems (McDonnell et al. 2004). In turn, epidemiologists and research teams can play a role in conflict prevention and reconciliation (Tschannen et al. 2005). Even if "health-peace" initiatives, launched for example by the WHO, did not have an impact at a large scale, it has been shown that they are beneficial not only for the health of the local people, but also for an enhanced community cooperation, and thus can be considered as a contribution to local reconciliation (Böck-Buhmann 2005; Santa Barbara & MacQueen 2004). In a climate of general insecurity, local health structures provide to some degree security and trust, as there is some familiarity with the health staff which creats mutual trust, and stable local centres can play a role in reaching marginalized groups (Barnabas & Zwi 1997; Kaba *et al.* 2006; Lee *et al.* 2006).

Researchers working in health-related fields can measure the extent and severity of the impact of complex emergencies, e.g. armed conflicts, on the health of civilian populations (Burnham *et al.* 2006; Guha-Sapir *et al.* 2005). It should be kept in mind that a major part of civilian mortality can be attributed to the fragility of the populations and not directly to the intensity of the conflict (Ghobarah *et al.* 2004; Guha-Sapir & van Panhuis 2003; O'Dempsey & Munslow 2006). A collaboration between scientists in health and political research would be an approach to focus attention of the international community towards a better protection of the population from the consequences of conflicts (Murray et al. 2002).

8.2.2 Significance for the NCCR North-South

- An important feature of our work was that it consisted of a multidisciplinary research approach, involving both quantitative and qualitative methodologies. The various parts of the research presented here were facilitated by multidisciplinary teams, consisting of biologists, laboratory technicians, health professionals, entomologists, agronomists, sociologists, epidemiologists and geographers, in order to apprehend the complexity of the contextual determinants contributing to parasitic diseases in urban farming communities.

- Our findings illustrate typical agricultural land use patterns and farming practices in different urban settings, and how agricultural activities and subsequent land use patterns might be related to the frequency and distribution of major human parasitic diseases.

The two case studies revealed the close connections between urban agricultural land use and specific parasitic diseases in urbanized areas of tropical West Africa.

- The outcomes from our research build a scientific basis for the design and implementation of environmental control strategies that hold promise to mitigate negative health effects of people living in neighbourhoods of agricultural zones. We propose farming-based environmental control measures that are integrated in a professional farming training provided by extension services. This approach can improve the livelihood of marginalized groups (i.e. urban farmers in Abidjan), and can reduce the risk of transmission of major parasitic diseases, such as malaria, schistosomiasis and soil-transmitted helminthiasis.

8.2.3 Risk mapping and the issue of scale

The categorization of crop types into market garden crops, rain-fed food crops, rice and perennial crops was a too coarse indicator for high-risk areas for *P. falciparum*, *S. mansoni* and hookworm infection in the small area of Man (5 x 7 km). It would be interesting to investigate if such classifications might be more useful for larger zones where data on environmental features and land use are provided by high-resolution satellite imagery, e.g. Landsat, given that specific man-made water bodies identified as productive *Anopheles* breeding and *S. mansoni* transmission sites were linked to typical crop systems (e.g. irrigation wells in market gardens). Furthermore, it would be interesting to investigate to what extent high-resolution satellite images, which can be obtained free of charge (e.g. provided by Google Earth) and provide highest resolution particularly in urban areas, can be used for the identification and monitoring of potential *Anopheles* breeding sites in open and cultivated green areas.

At the micro-level (e.g. neighbourhoods within a village, town, or city district), high-resolution satellite and aerial images represent a useful tool for the rapid identification of potential mosquito breeding sites and snail habitats, as studies from different settings have shown (Dale & Morris 1996; Mushinzimana *et al.* 2006; Sattler *et al.* 2005). At the district level, land use classifications using remote sensing (RS) and GIS methods have been applied to identify landscape elements that can explain *Anopheles* abundance, e.g. in the Chiapas region, Mexico (Beck et al. 1994). Plant growth stages in rice paddies that provided highly productive mosquito breeding sites were identified in California, using remotely-sensed spectral reflectance Landsat TM data (Wood et al. 1992). At a large scale, GIS and remote sensing technologies are important tools to produce risk and prediction maps within eco-zones showing the spatio-temporal heterogeneity of parasitic infectious diseases, and to identify environmental factors associated with infection risk (Yang et al. 2005). Such maps can help to locate and estimate target populations for disease control. Recent examples include malaria in West Africa (Gemperli *et al.* 2006; Kleinschmidt *et al.* 2001), schistosomiasis in Tanzania and Côte d'Ivoire (Brooker et al. 2001; Raso et al. 2005a) and soil-transmitted helminthiasis in Cameroon (Brooker et al. 2002).

In summary, small and medium-scale epidemiological studies done at the community or district level can identify and to some extent predict town districts and communities that are at high risk of parasitic diseases. Risk maps then help to guide decisions of health planners for spatial targeting of control interventions. Large-scale studies are important to predict epidemics, for example linked to weather and seasonal climatic situations in the case of malaria (Mabaso et al. 2005; Thomson et al. 2006). As a whole, studies at different spatial scales are needed for a better understanding of how the different scales interact, including the dynamics and causes of changing patterns (Levin 1992).

8.2.4 Bayesian spatial modelling

We used Bayesian statistical approaches integrating spatial correlation of infection at a small-scale level to explain the heterogeneity of *P. falciparum*, *S. mansoni* and hookworm infections in farming communities in Man. At least three aspects are worth mentioning. First, results from different models revealed that infection was not spatially correlated, as spatial correlation was only important within a few meters. Second, environmental parameters derived from satellite data, such as rainfall, are too wide-stretched to remain significant at micro-scale in contrast to human behavioural factors that play an important role. Third, distance to permanent fish ponds, ponds and the Kô River, and living in specific agricultural zones were identified as small-scale environmental risk factors for *P. falciparum*, *S. mansoni* and hookworm infections, respectively. Bayesian approaches at small-scale level could be useful for malaria studies, that is, for the understanding of the local ecology of vector-human interactions. For *S. mansoni* and hookworm, similar studies could give more insight into infection patterns. From a morbidity control perspective targeting larger communities, this approach might be of limited use, since soil-transmitted helminthiasis and schistosomiasis are rather related to human behaviour.

In Bayesian statistics, the data is set as fixed because data are known, whereas unknown parameters are considered as random. The inference about model parameters is made conditional on these fixed data. Information from previous studies can be integrated via an informative prior distribution. For example known statistics from previous studies carried out in the same area can be used as a prior probability distribution in a new study. With this approach, multiple sources of data and uncertainty can be incorporated within a single model, and the estimation or prediction of parameters of small sample size-studies can be improved (Basáñez *et al.* 2004; Dunson 2001). Bayesian statistical approaches for the modelling and prediction of the spatial risk of infection can represent a helpful guide for integrated disease control programmes. Such approaches have been applied in studies of broad scale, e.g. for the spatial distribution of malaria in Mali (Gemperli et al. 2006). Numerous risk and prediction maps have been produced at medium-scale setting at district level, i.e. for *S. mansoni* in western Côte d'Ivoire and (Raso et al. 2005a; Raso et al. 2006) and *S. mansoni* and *S. hematobium* in northwest Tanzania (Clements et al. 2006). However, there is a paucity of small-scale studies using Bayesian statistics. One recent study investigated micro-scale heterogeneity of soil-transmitted helminths in Brazil (Brooker et al. 2006).

Based on the results of our studies, we recommend investigating if Bayesian statistical approaches might be useful to explain spatial heterogeneity of human parasitic infections at micro-scale and if such approaches might represent a decision tool for the design of control programmes that are readily adapted to local agro-ecological settings.

8.2.5 Comparison of parasitological outcomes between different study settings

A comparison of the main outcomes between the three study settings has to be done with utmost care, given the largely diverse contextual determinants. In the present section, the profiles of parasitic infections and identified risk factors are discussed.

P. falciparum and hookworm infections were markedly lower in the two urban settings compared to the village of Zouatta II. In contrast, the profile of *S. mansoni* and soil-transmitted helminth infections was quite similar in the village of Zouatta II and in Man, with a high prevalence of *S. mansoni* and low levels of *A. lumbricoides* and *T. trichiura* infections. In Abidjan, on the other hand, *T. trichiura* and *A. lumbricoides* prevalences were considerably higher. A common risk factor for *P. falciparum* infection in the village of Zouatta II and in Man was close proximity to permanent water bodies. *S. mansoni* and hookworm infections were associated with rice cultivation and shared transmission sources in agricultural, and, for hookworm, in domestic domains. In both urban settings, the hookworm prevalence varied significantly between the agricultural zones and between farming and non-farming households, corroborating the results from other investigations that hookworm infection is related to agricultural activities. *A. lumbricoides* and *T. trichiura* infections, in contrast, could not be linked explicitly with farming activities, which suggests that the domestic and public domains play comparable important roles in transmission patterns. The quasi-absence of *S. mansoni* infection in Abidjan can be explained by the absence of the intermediate host snail. Systematic mosquito breeding site assessments in the rainy and dry season in agricultural zones of Man and in Abidjan showed that *Anopheles* larvae were very common and widespread regardless of the season. We assume that mosquito breeding sites in urban zones are more likely to be exposed to domestic waste than in rural areas and that larvae might adapt progressively to man-made ecologic niches, as observed elsewhere (Chinery 1984; Sattler *et al.* 2005; Trape & Zoulani 1987).

8.3 References

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9. Conclusions and recommendations

9.1 Conclusions

Our results suggest that the socio-political unrest had little effect on changes in agricultural land use in Abidjan, probably due to a slowed down construction pace. However, farmers' insecure permit status, land and livelihood entitlements worsened the economic vulnerability of the farmers and their families. The spatial extension of the agricultural areas in the town of Man probably increased the risk of malaria and schistosomiasis, as specific irrigated crop types and associated man-made water bodies may enhance malaria transmission in inhabited areas. High prevalences of soil-transmitted helminth infections among farming and nearby non-farming families in Abidjan indicate a precarious domestic and peri-domestic sanitary environment in these poor settlements. The socio-economic status of the farming households and related housing conditions as well as the domestic environment affected the households' susceptibility to malaria, soil-transmitted helminth and intestinal protozoan infections. The households' preoccupations were strongly underscored by the current political situation with their priority to maintain the household livelihoods and food security. Locally varying agricultural practices probably influenced the transmission of the investigated parasitic diseases; hookworm infection was gender-related and associated with agricultural practices. Schistosomiasis was linked to the contact with infested water bodies in rice paddies. Urban-rural migration in Man was a predictor for *P. falciparum* infections, and shared water sources emerged as a risk factor for both hookworm and intestinal protozoa in the village of Zouatta II.

With an emphasis on malaria and schistosomiasis, our observations and reported case studies from other urban settings conjecture that malaria vectors and intermediate host snails for schistosomiasis may adapt gradually to urban ecologic environments. Further on, urban agriculture as a livelihood might be associated with a high risk of malaria, schistosomiasis and hookworm in urban areas. An enhanced understanding of the epidemiology and transmission dynamics of vector- and water-related human parasitic diseases in urban areas is justified taking into consideration the predicted rapid growth of small towns in the near future and changing local ecosystems including the adaptation of intermediate host snails and vectors. In-depth studies may contribute to the design of improved treatment, prevention and control interventions that are readily adapted to local urban settings.

9.2 Recommendations

9.2.1 Urban malaria control

The complexity of urban malaria and its interactions within a network of environmental, ecological, political, economical, cultural and social factors requires a multidisciplinary research approach, combining quantitative and qualitative research methodologies for a better understanding of the variables that interact at different scales (Carrasquilla 2001). Social science research contributes to apprehend behaviours of actors and stakeholders, which in turn can aid in the translation of the extracted knowledge by researchers into improved designs and implementations of malaria prevention and control interventions (Mwenesi 2005). "Pillar strategies" of rolling back urban malaria rely on the enhanced knowledge of transmission patterns and disease burden in different urban contexts, appropriate rapid malaria diagnosis and treatment (Wang et al. 2005), and the coordination between different stakeholders (e.g. governmental agencies at different levels, researchers and local communities) (Carrasquilla 2001).

Sound environmental management for vector control (e.g. construction and maintenance of drainage canals, draining of flooded and swampy areas and vegetation clearance) showed a high reduction of potential breeding sites in urban areas where small-scale heterogeneity of transmission was a typical feature (Castro *et al.* 2004; Keiser *et al.* 2005; Utzinger *et al.* 2001). Larval control holds potential as an effective complementary strategy to adult vector control, since larvae and pupae are bound to aquatic habitats limited in size (Fillinger & Lindsay 2006; Killeen *et al.* 2002). Community-based integrated vector management (IVM) where local community-based organizations and ecologists collaborate has been proposed as a means to facilitate vector control (Mukabana et al. 2006). The training of farmers in malaria control strategies via a Farmer Field School System (FFS), complementing the integrated pest and vector management (IPVM) has been tested successfully in rural areas in Sri Lanka (van den Berg & Knols 2006). An adaptation of this approach to urban settings would make sense once more evidence is provided that the bulk of *Anopheles* breeding habitats is identified effectively in agricultural areas. A sound training of the community-based staff is crucial to achieve high coverage of the detection and elimination of *Anopheles* larvae with a comparable impact (Vanek et al. 2006).

9.2.2 Control of urban schistosomiasis, soil-transmitted helminthiasis and intestinal protozoa

The main approach to control morbidity due to soil-transmitted helminthiasis and schistosomiasis builds on school-based periodic de-worming programmes. However, soil-transmitted helminths, in particular hookworm infections, are characteristically household-clustered and also occur in adults (Brooker et al. 2004). Hence, a community-based control needs innovative locally-adapted strategies to target additional high-risk groups, i.e. pre-school children and pregnant women who are particularly vulnerable to iron-deficiency anaemia. Farmers also seem to be at high risk due to their exposure during daily farming activities. Non-specialized health staff, for example schoolteachers and local community workers, can administer treatment, provided that health specialists give appropriate tailored training. Due to short re-infection intervals, treatments need to be repeated frequently (Brooker et al. 2004; Lammie et al. 2006). Thus, chemotherapy only represents a temporary relief and sustainable solutions for the control of schistosomiasis and helminthiasis can only be achieved by improved water supplies, sanitation and hygiene conditions (Cairncross & Valdmanis 2006; Utzinger *et al.* 2003).

9.2.3 Proposed actions and current research

For Man, we recommend an integrated community-based control programme targeting malaria, schistosomiasis, and soil-transmitted helminths, and for Abidjan a better collaboration between local agricultural extension services and health structures. Proposed action and research components are outlined below:

- *Community-based control of soil-transmitted helminthiasis and schistosomiasis*

  Our results indicate that the town of Man is a high-prevalence area of *S. mansoni* according to the WHO (threshold: 50%), where mass treatment of the population is recommended (WHO 2002). We thus propose community-based mass treatment for schistosomiasis and soil-transmitted helminthiasis. This strategy, which complements the school-based approach and has successfully been applied for example in Burkina Faso (Gabrielli et al. 2006), is justified for Man as well as for Abidjan in order to reach also a considerable percentage of those children who are not able to attend school (44% in 2005 at national level) (United Nations office for the coordination of humanitarian affairs 2005). On a long-term basis, agricultural extension services could be integrated in the provision of effective treatment for schistosomiasis and soil-transmitted helminths of farming households.

- *Strengthening local health systems and local agricultural organizations*

Local health systems and local agricultural structures (e.g. informal farmer communities) need a stronger support by the Ministries of Health and Agriculture, for example by means of national extension services such as the ANADER. This strategy will allow local institutions to take an active role in prevention and effective treatment provision at community level. The fact that only every fifth household in the studied farming communities owned bed nets (which does not yet imply their use), warrants better integrated social marketing and commercial strategies to provide ITNs for local communities (Kikumbih *et al.* 2005; Nathan *et al.* 2004). Local agricultural structures, in collaboration with national extension services, could provide consultation and training in techniques of rice cultivation and vegetable production, integrating environmental control methods to eliminate vectors and intermediate host snails that are simple, cheap and applicable by the farmers themselves.

- *Research*

  We propose an in-depth study in two selected zones in the town of Man (zone 5 of a large rice perimeter with ≥ 2 annual crop cycles and a low habitation density, 1 zone with a high habitation density and near the Kô river), which aims to enhance the understanding of transmission dynamics and interactions of malariological parameters in agricultural and non-agricultural zones. The proposed study ties up with research on irrigated rice cultivation and malaria that has been carried out in rural areas of Côte d'Ivoire by the WARDA (Briët et al. 2003; De Plaen et al. 2003). The methodology should comprise repeated systematic appraisals of mosquito breeding sites, repeated mosquito collections and measuring malaria incidence (entomological inoculation rate, EIR), and should be accompanied by a study on mosquito-avoidance practices (Minja et al. 2001). In addition, we propose malacolocical surveys to assess the spatial and temporal distribution of infected *Biomphalaria* and *Bulinus* host snails in major water contact sites, and involving the farmers in survey and control activities to reduce the density of snail hosts (Kloos et al. 2001).

- *Larval control in Abidjan*

  We recommend an intervention study to test simple methods of *Anopheles* larval control in two selected agricultural zones (1 intervention and 1 control zone). Proposed control interventions are (i) covering irrigation wells with empty barrels (e.g. oil drum), (ii) treatment of wells with larvicides, and (iii) covering wells with with floating plants.

We will examine if the covered wells hold additional advantages (e.g. stability and durability, less water-exposure of farmers). In addition, the provision of ITNs and drug treatment for soil-transmitted helminths by the ANADER in these zones should be discussed with different stakeholders.

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Basel, June 2007