

MARA
Mapping Malaria Risk in Africa



ARMA
Atlas du Risque de la Malaria en Afrique

Towards an Atlas of Malaria Risk in Africa

First Technical Report of the MARA / ARMA Collaboration

MARA / ARMA, Durban, 1998

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Cover: *Plasmodium falciparum* infected red blood cells,
Anopheles arabiensis mosquitoes,
and children in Edendale Hospital, South Africa



Preface

It is with great pleasure that I write this preface for the first technical report of the MARA /ARMA (Mapping Malaria Risk in Africa / Atlas du Risque de la Malaria en Afrique) project. The reason for this pleasure is twofold: Firstly, the MARA /ARMA project is an example of African collaboration and cooperation at the continental scale through the creation and functioning of an African scientist network. This is proof that, by joining efforts in Africa, using our local expertise, we can progress considerably in our endeavour to roll back malaria illness. Secondly, the MARA /ARMA project was able to seize the opportunities offered by new technologies such as "Geographical Information Systems", in order to develop a product which will be of prime importance in the epidemiological surveillance of malaria in Africa. This first technical report illustrates these achievements.

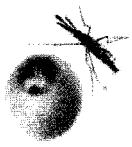
At a time when the fight against malaria is regaining interest among the international community, and when major new initiatives such as the "African Initiative on Malaria" or "Roll Back Malaria" are being established, I would like to congratulate the report's authors and collaborators for their contribution to this piece of work.

The development of the final products (the detailed malaria endemicity maps, and in particular maps identifying regions with epidemic malaria potential) required the field collection of a vast amount of information. It is not always easy to find existing information. The MARA /ARMA products will allow us to better understand the distribution of malaria in Africa, at both the country and regional levels. This is a formidable planning and management tool now available to malaria control programmes.

Beyond disease distribution maps, readers will find in this first technical report the outline of a unique epidemiological and climatological database accessible to various audiences, including health programme managers, epidemiologists, medical doctors, and researchers. Even better, the malaria transmission models that are being developed will allow users to foresee, with a minimum of information, the transmission dynamics in a given zone and thereby to take appropriate measures in anticipation.

It is my wish that the work which has been initiated will be completed and, above all, that all national malaria control programmes will make good use of it.

Dr Ebrahim M. Samba
Regional Director
WHO-AFRO



Préface

C'est avec un très grand plaisir que je préface ce premier rapport technique du projet MARA /ARMA (Mapping Malaria Risk in Africa / Atlas du Risque de la Malaria en Afrique). Ce plaisir, on le comprendra, je le dois à deux raisons essentielles : d'abord, le projet MARA /ARMA est un exemple de collaboration et de coopération africaine, à l'échelle continentale, avec la création et le fonctionnement d'un réseau de chercheurs africains. Ceci constitue une preuve qu'ensemble en Afrique, avec la contribution de nos compétences locales, nous pouvons réaliser des progrès considérables et faire reculer la maladie. Ensuite, le projet MARA /ARMA a su saisir les opportunités qu'offrent les nouvelles technologies comme le "Geographical Information System", pour concevoir et réaliser un produit, qui sera de toute première importance dans la surveillance épidémiologique du paludisme en Afrique. Ce premier rapport technique en est une illustration.

Au moment où la lutte contre le paludisme reprend de l'intérêt au sein de la communauté internationale et où se concrétisent des initiatives d'envergures, telles que l' "Initiative Africaine pour la lutte contre le paludisme au 21 ème siècle" et le "Roll Back Malaria", je voudrais féliciter les auteurs et tous ceux qui sont impliqués dans ce projet, pour le travail accompli.

En effet, le résultat final que sont entre autres les cartes détaillées sur l'endémicité du paludisme et surtout la cartographie des zones à potentiel épidémique a nécessité la collecte d'une masse très importantes d'informations sur le terrain. Il n'est pas toujours facile de retrouver ces informations. Les produits du projet MARA /ARMA permettront de mieux connaître la distribution du paludisme en Afrique, dans un pays, dans une région. En cela, ils sont de formidables outils de planification et de gestion des programmes antipaludiques.

Au delà de la cartographie, les lecteurs trouveront en ce premier rapport technique, la description d'une base de données climatologiques et épidémiologiques unique, utilisable par les planificateurs des programmes de santé, les épidémiologistes, les médecins et les chercheurs, entre autres. Mieux encore, les modèles statistiques développés sur la transmission du paludisme permettront aux utilisateurs, de pouvoir prévoir, avec un minimum d'informations, la dynamique de la transmission du paludisme dans une zone donnée et ainsi anticiper les mesures à prendre.

Il reste à espérer que le travail qui a débuté soit conduit à son terme, et surtout que tous les programmes nationaux de lutte contre le paludisme en fassent la meilleure utilisation possible.

Dr Ebrahim M. Samba
Directeur Régional de l'OMS pour l'Afrique



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Acknowledgements

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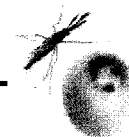
The production of this document has been sponsored by the South African Medical Research Council.

Recently, the MARA/ARMA collaboration has been the recipient of a Multilateral Initiative on Malaria (MIM) award.

A special thanks to Colleen Fraser for her significant contribution in maintaining the central MARA/ARMA database, and to Carrin Martin for logistical support.

Many individuals have contributed to the success of MARA/ARMA so far. A list of individuals who have contributed data or helped locate information is contained on the inside back cover.

This technical report constitutes the first summary document prepared by the MARA/ARMA collaboration. It aims to give an overview of activities and progress. Although great care has been taken in its preparation, it is likely to be incomplete and incorrect in some points. We welcome inputs, both on this document and on the MARA/ARMA initiative in general. Comments can be most easily sent using attached questionnaire. Comments from malaria control workers and malaria researchers in endemic areas are especially welcome.



List of Abbreviations

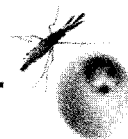
ARMA	Atlas du Risque de la Malaria en Afrique	NDVI	Normalized Difference Vegetation Index
EIR	Entomological Inoculation Rate	NGO	Non-governmental Organization
GIS	Geographic Information System	PR	Parasite Ratio
HIMAL	Highland Malaria Project	RBM	Roll Back Malaria
IDRC	International Development Research Centre	TDR	Research and Training in Tropical Diseases
ITN	Insecticide Treated Net	WHO	World Health Organization
MARA	Mapping Malaria Risk in Africa project	MIM	Multi-lateral Initiative for Malaria
MRC	Medical Research Council	MOH	Ministry of Health

Glossary

boolean logic	logic system based on whether something exists or not, i.e. a Yes/No or a one/zero situation. It covers concepts like "intersection" (\cap) and "union" (\cup) of data sets, and involves logical arguments such as a AND b , a NOT b , a OR b , etc.
data surface / coverage	GIS data in the form of a grid, covering an area on earth, in which every grid cell contains a data value for its specific location
data point	one set of results in the MARA/ARMA database, unique in time, origin, locality and methodology; it can only be sub-divided into different age-categories.
EIR	entomological inoculation rate: the number of infectious mosquito bites a person is exposed to in a certain time period, typically a year
endemic malaria	measurable transmission and incidence every year
epidemic malaria	occasional malaria outbreaks in normally malaria-free regions; a particularly severe malaria season in a normally low-risk area
fuzzy logic	a logic system which is an extension of boolean logic, in which fractions between zero (No) and one (Yes) express the extent or degree to which something exists.
geo-reference	measure / record the position on earth in longitude and latitude; allocate geographical coordinates
GIS	geographical information system: computer programmes that combine spatial and descriptive (attribute) data for mapping and spatial analysis
incidence	number of new cases (of clinical disease or parasitaemia) recorded over a certain time period in a defined population



infection rate	number of new infections acquired over a defined period of time
NDVI	normalized difference vegetation index: a satellite derived index which gives a measure of the "lushness" of plant growth
parasitaemia	presence of parasites in the blood; number of parasites per volume of blood
parasite ratio	percentage of survey population testing positive for malaria
prevalence	see "parasite ratio"
sporogonic cycle	sexual development of / incubation period of malaria parasite in mosquito; time required for a mosquito to become infective after feeding on an infected person
species complex	group of species which are partially or completely identical in appearance (morphologically), but which differ genetically
stable malaria	see "endemic malaria"
transmission	spread of malaria by completion of a full transmission cycle (man - mosquito - man)
unstable malaria	see "epidemic malaria"



Foreword

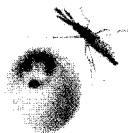
Most members of the GIS-Health community would have experienced the scepticism of many, regarding the value of GIS as a useful tool for health research and intervention. The merits of this debate regarding the value of GIS in health will not be covered here. Needless to say the inception of MARA/ARMA was faced with a similar scepticism by many in terms of the ultimate value of such an approach, its logistical feasibility and cost effectiveness. Considerable credit must thus be given to the International Development Research Centre (IDRC) and specifically Dr Don de Savigny for being willing to invest in what many would have considered a "high risk venture". This report reflects the collaboration's output using this initial seed funding of US\$ 200 000 as well as some supplementary funding from the South African Medical Research Council (SAMRC) and the Wellcome Trust.

The National Malaria Research Programme (SAMRC) GIS effort was started in 1989 with very limited funding and with the focus of mapping malaria risk in South Africa, towards more targeted control. With the continued support of the programme leader, Dr Brian Sharp, the division has developed a core expertise in GIS and database management. It was this expertise which was recognised by Dr Don de Savigny following the IDRC sponsored meeting on GIS for Health and the Environment in Sri Lanka, 1994 (de Savigny and Wijeyaratne, 1995). Subsequent discussions between himself and Dr Bob Snow concerning the need for an initiative such as MARA/ARMA resulted in two small workshops funded by the WHO/TDR Task Force on ITNs and IDRC respectively. The conceptual proposal was developed at an initial meeting consisting of Fred Binka, Bob Snow, Christian Lengeler and myself. The second workshop at which the full proposal was developed, included a larger group of 15 people (entomologists, epidemiologists, geographers).

The subsequent growth and success of MARA/ARMA must however be attributed to the dedication of the co-investigators and data co-ordinators at the regional centres and their data sources. I would specifically like to mention the initial momentum provided by Dr Bob Snow in terms of the development of the data proforma and Colleen Fraser for capturing this into the stand alone data application. This was a critical first step in getting the collaboration operational and in ensuring standardisation. Subsequent important steps were the search for baseline digital data sets and the training of regional staff in Durban. There are many others to thank but I would like to mention Marlies Craig who has shown exponential ability in terms of her acquisition of much needed raster GIS skills and Carin Martin for consistent logistical support. It was a privilege to work with African scientists of the calibre of the MARA/ARMA regional co-ordinators and co-investigators.

I believe that MARA/ARMA and this 1st preliminary product is a good example of how GIS can be usefully employed in health in a cost-effective manner and is an outstanding example of a networked collaboration. It contains all the essential components including a robust database and an understanding of disease determinants and their spatial scale.

The future of MARA/ARMA is now secure with the recent grant of the Multi-lateral Initiative for Malaria (MIM) as well as the co-funding of the Highland module by the TDR task force for Health and the Environment. A measure of recognition is the recent decision by Roll Back Malaria (RBM) to place a staff member at the co-ordinating centre in Durban, to support RBM activities. The central challenge that lies ahead for the collaboration is the dissemination of existing and new products and GIS skills that will contribute significantly to new initiatives against malaria, such as MIM and RBM. In the research arena MARA/ARMA will need to work more closely with climatologists towards a better understanding of unstable malaria and its prediction.



In conclusion Health GIS is a research field which is in its infancy and constitutes an approach which has little applicability in certain diseases. There is however no doubt that in the case of environmental vector borne diseases such as malaria, a GIS approach is highly appropriate

David leSueur
Principal Investigator
MARA/ARMA collaboration



Executive Summary

Sub-Saharan Africa carries the highest per capita burden of disease in the world. Of this malaria is the single most important disease, being responsible for nearly one million deaths and 300-500 million clinical cases every year. The control of malaria is now gaining momentum in Africa after decades of neglect, against a background of lack of preventive measures, weak health services and increasing drug resistance. Large-scale control activities will require not only effective tools and strategies, but also reliable statistics on (1) the distribution limits of endemic and epidemic malaria, and (2) populations at risk at each endemicity level.

The distribution, transmission intensity and clinical consequences of malaria in Africa vary greatly across the continent. Africa experiences a complete spectrum of malaria epidemiology ranging from intense perennial transmission to unstable, epidemic-prone areas. This has implications for the planning, targeting and implementation of control activities at continental, national and regional levels. Despite the importance of these facts, a continental perspective of where (distribution), how much, (transmission intensity), when (seasonality), why (environmental determinants) and who is affected (populations at risk) does not currently exist.

The Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique (MARA/ARMA) collaboration was created to fill this gap and to establish a continental database of the spatial distribution of malaria in Africa. To achieve this aim it relies on two complementary approaches:

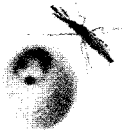
A. The formation of a continental database of available malariometric data representing precisely geographically positioned survey data from published and unpublished sources in 44 countries.

The largest possible number of existing malaria survey data are being collected from published articles, university theses, ministry reports and unpublished work by research and other institutions. Parasite ratio data in children are by far the most commonly available data in Africa and MARA/ARMA has therefore focussed on them. Data on other transmission indicators such as entomological inoculation rates and infant parasite surveys are also being collected. Incidence rates derived from routine statistics will only be used in the few countries with reliable health information systems. In order to carry out this large data collection exercise MARA/ARMA has established five regional (and two sub-regional) centres, each with a data collector. These centres have also been equipped with Geographic Information System (GIS) skills and digital data sets necessary to geo-reference the collected data.

B. The development of environmentally determined models of continental limits of transmission risk, in order to supplement the data collection of empirical data in areas where no such data exist.

Malaria distribution, seasonality, frequency and transmission intensity is being investigated at various spatial scales. This approach has provided an immediate starting point for describing malaria epidemiology on a continental and national scale.

Both approaches are complementary and the empirical data have been used to develop and validate models in a number of countries. The malaria maps have been combined with other data sets such as population and administrative boundaries, thus providing a fundamental resource for planners (district-national-regional level), donors and researchers.



MARA/ARMA is a unique example of a Pan-African collaboration of researchers and control managers. The first products of the MARA/ARMA collaboration are now being distributed. The collection of basic malaria data and risk maps are providing national governments, donors and international agencies with a more empirical basis for evidence-based, strategic planning for malaria control. Complementary projects aiming to describe highland malaria and to establish a malaria vector map for Africa are also part of the MARA/ARMA collaboration. Through a closer collaboration with malaria control programmes and scientists on the continent the collaboration will build upon these experiences to assist the global efforts to Roll Back Malaria into the next millennium.



Résumé

En comparaison internationale, la santé d'un habitant de l'Afrique sub-saharienne est actuellement la plus mauvaise dans le monde. Sur ce continent, la malaria est actuellement la principale cause de morbidité et de mortalité, responsable pour un million de décès et 300-500 millions de cas cliniques par an. Le contrôle de cette maladie connaît actuellement un regain d'intérêt après des années d'inaction. Malheureusement cela arrive dans un contexte caractérisé par l'absence de mesures préventives, la faiblesse des systèmes de santé en place, et des taux élevés de résistance du parasite aux médicaments courants. La planification et l'exécution du contrôle de la malaria à une large échelle demandent bien sûr des outils et des stratégies de lutte effectifs, mais aussi des statistiques fiables sur (1) la distribution du paludisme endémique et épidémique et (2) une estimation des populations à risque à chaque niveau d'endémicité.

La distribution et l'intensité de la transmission du paludisme sont loin d'être homogènes en Afrique. L'on trouve en Afrique un large spectre de situations épidémiologiques, de la malaria pérenne de haute intensité à la malaria instable épidémique. Cela est d'importance pour la planification, la hiérarchisation et l'implantation des activités de lutte aux niveaux continental, national et local. Malgré l'importance de ces aspects géographiques notre compréhension actuelle de la distribution (où ?), des déterminants (pourquoi?), de la quantification (combien?) et de la saisonnalité (quand?) de l'endémicité palustre est très imparfaite.

L'objectif principal de la collaboration Mapping Malaria Risk in Africa / Atlas du Risque de la Malaria en Afrique (MARA /ARMA) est d'établir une base de données à l'échelon continental sur la distribution du risque de la malaria. Deux approches principales sont utilisées pour atteindre cet objectif.

A. Une collection aussi complète que possible de données paludométriques existantes pour le continent est constituée pour 44 pays. Chaque point est défini géographiquement de manière précise.

Les sources utilisées sont les publications scientifiques, les thèses universitaires, les rapports de ministères et les documents produits par des organisations de recherche ou de développement. Les données de prévalence parasitologique sont de loin les données les plus largement disponibles et la collaboration MARA /ARMA s'est concentrée sur ces dernières. Toutefois, d'autres données telles que des données de transmission entomologique, et les taux de parasitémie chez les nourrissons sont aussi collectées. Les données sur l'incidence des cas de malaria provenant des statistiques de routine des ministères de la santé n'ont été collectées que dans un petit nombre de pays où ces statistiques sont réputées fiables. Afin de conduire ce large exercice de collecte, la collaboration MARA /ARMA a établi cinq centres régionaux (et deux centres annexes) avec dans chacun de ces centres un collecteur employé à plein temps. Ces centres ont été équipés avec des Systèmes d'Information Géographiques (SIG) et le personnel formé à leur utilisation.

B. La deuxième approche repose sur une modélisation de facteurs climatiques visant surtout à compléter la collecte des données paludométriques dans les zones où ces données ne sont pas disponibles.

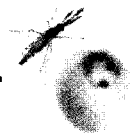
La distribution de la malaria, sa saisonnalité et l'intensité de la transmission ont ainsi pu être étudié à diverses échelles géographiques. Ceci a permis de donner rapidement une première description de la transmission de la malaria à l'échelle du continent .



Ces deux approches sont complémentaires et les données paludométriques ont été utilisées pour valider le modèle climatique dans quelques pays. Ces cartes ont été combinées avec d'autres données (démographiques et administratives) pour produire de cartes intégrées utilisables dans le cadre des activités de lutte à divers échelons.

MARA /ARMA est un exemple unique de collaboration panafricaine entre des chercheurs et des personnes travaillant dans des programmes de contrôle. Les premiers produits de cette collaboration commencent à être distribués. Les cartes malariométriques vont ainsi fournir aux programmes de contrôle gouvernementaux, aux donateurs ainsi qu'aux agences internationales une base de données utilisable pour une planification plus rationnelle des ressources et activités. Deux projets additionnels sur la malaria d'altitude ("highland malaria") et sur la cartographie des anophèles vecteurs font aussi partie de la collaboration MARA /ARMA.

A travers une collaboration plus étroite entre les chercheurs et les programme de contrôle l'expérience accumulée servira à soutenir les efforts actuellement en cours pour améliorer le problème du paludisme en Afrique.



Chapter 1

About MARA /ARMA

Introduction

Malaria - the Problem

Malaria poses an enormous problem in Africa. It is estimated that malaria causes 1-2 million deaths and 300-500 million clinical episodes annually (World Health Organization, 1994). Of the global deaths due to malaria about 90% now occur in Africa. A similar picture is seen for clinical episodes. This situation results both from the particular epidemiological situation in Africa and the nearly total absence of systematic control activities during the past decades. As a result, the burden of the disease on societies and economies is tremendous.

Fortunately the situation has recently been receiving renewed attention by national and international health and funding organizations. In particular, the recent call by the new Director-General of the World Health Organization, Dr Brundland, to "Roll back malaria" is encouraging in this respect. The development of continental to district planning tools is therefore very timely.

New Hope for Malaria Control

Recent public health technologies offer, for the first time in decades, real opportunities to greatly reduce the burden of disease in the African context. For instance, new drugs and improved formulations and packaging are gradually allowing improved symptomatic treatment at the household level. As a preventive measure the large-scale use of insecticide treated nets (ITNs - bednets and curtains) has provided new tools to tackle morbidity and mortality from malaria. ITNs have been shown recently to reduce overall child mortality by between 14 and 63 % in various endemic settings, making this intervention extraordinarily cost-effective. Whilst there remain great hopes for a vaccine, the next generation of vaccines will not be available for widespread delivery for a number of years, and the single

most important strategy remains the provision of effective treatment early during the clinical course of infection. These tools now need to be deployed in the most effective way.

Many factors affect the choice of malaria control methods in a region: endemicity, vector species and behaviour, seasonality, disease patterns, health services factors and more. Since all these factors are not distributed equally across the continent, accurate, relevant and timely information on them is required before malaria control can be planned and resources allocated properly.

For this purpose, maps offer an ideal way of displaying complex information in a way that is intuitively understandable and instructive. Some factors, such as the availability of health and malaria control services and existing infrastructures, can be simply mapped to give a visual representation of information already available in non-spatial format. For other factors, such as malaria endemicity, disease patterns, vector distribution or seasonality, spatial methods may be used to produce seamless data surfaces (where information is available for every point in space). Such continuous data coverages provide information in a format that is relevant both at the continental scale, where it provides a quick overview of the situation, down to the national and sub-national level, where it provides detailed guidance and answers specific questions. In both cases problems can be tackled in a systematic and informed way.

Mapping Malaria

The Need for Maps

Mapping malaria endemicity is crucial for a number of reasons. Firstly, areas without risk of malaria need to be identified, while areas with epidemic malaria need to be highlighted and integrated into an adequate early warning



system. This is a very fundamental and important undertaking in order to define the size of the malaria problems in each country.

Secondly, in areas of endemic malaria, the pattern of severe malaria disease has been shown to vary according to the intensity of the transmission (Snow *et al.*, 1997). In areas with lower levels of endemicity the disease pattern was found to be dominated by cerebral disease forms in older children (over 2 years of age) while in areas of very high transmission the disease pattern was dominated by severe malaria anaemia in young children and infants. This age-dependence of malaria disease according to the intensity of malaria transmission has great practical importance for the preventive and curative services since both the target age group and the clinical care need to be adopted.

Thirdly, the protective effect of control measures such as ITNs might be related to initial level of transmission intensity, although the total number of lives saved by the intervention in the four recently completed trials in Africa was remarkably similar in all settings (Lengeler, 1998). Other measures such as larviciding might only be viable in highly seasonal or fringe areas where the mosquito populations are sufficiently unstable to be affected by such interventions. Vaccines may become particularly effective in areas of very high endemicity, where the initial boost of immunity offered by the vaccine will then be sustained by the immuno-response to frequent inoculations in high-transmission zones. In-door insecticide spraying has to be applied according to the seasonality of malaria transmission - both in terms of timing and choice of insecticide. A chemical effective for nine months is useless in areas of perennial transmission.

Mapping - Past and Future

Mapping disease has a long history, starting with John Snow's work on cholera in Victorian London. Not surprisingly, mapping has been widely applied for even the rarest diseases in industrialized countries, while remarkably little has been done on the major infectious diseases that

still dominate today's disease burden in the world. In the case of malaria in Africa a few national maps have been produced (South Africa, Kenya, Tanzania, Uganda) on the basis of expert opinion, in some instances backed up by extensive field work (Clyde, 1967).

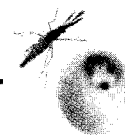
In spite of the enormous problem malaria is causing in Africa, there is a scarcity of basic data and a lack of understanding of the situation. Details on malaria risk and severity, and fundamental perspectives of where (distribution) why (environmental determinants) how much (transmission intensity) and when (seasonality) malaria occurs, do not exist. No-one has attempted to define which populations are truly exposed to risk of malaria. In addition, the lack of accurate diagnostic methods and reporting systems has resulted in unreliable records of malaria-caused death and sickness from routine sources.

We therefore need to rethink how to define endemicity and how we may map malaria risk in order to better support planning and programming of malaria control. In view of the renewed interest in the control of malaria in Africa such maps need to be drawn up systematically for the entire continent.

Providing timely and adequate data is an essential pre-requisite of evidence-based planning which is increasingly applied to all areas of public health. This necessity is at the core of the Mapping Malaria Risk in Africa/Atlas du Risque de la Malaria en Afrique (MARARA/ARMA) Collaboration. The purpose of this technical report is to present the MARARA/ARMA collaboration and its initial products, and to solicit feedback from potential users.

MARARA/ARMA: an International Collaboration

The MARARA/ARMA collaboration was initiated to provide an atlas of malaria risk for Africa, i.e. a continental database of the spatial epidemiology of malaria, through the use of a



personal computer-based Geographic Information System (GIS), by integrating different malaria, geographical and environmental data sets.

From the start the MARA/ARMA collaboration has been an international and inter-disciplinary undertaking (with biologists, medical doctors, statisticians, geographers), initiated by a group of malaria researchers active in Africa, with close links to national malaria control programmes. Today we have a real opportunity to develop a dynamic atlas of disease risk and severity through international collaboration. This has been due to the availability and affordability of GIS software, Internet connectivity in Africa, a spirit of international collaboration, growing emphasis on evidence-based planning and increasing availability of global data sets (population, climate, satellite imagery, etc.)

Double Focus

From the start, MARA/ARMA has been set up on two complementary approaches: an empirical data collection and geographical modelling.

A Empirical Data Collection

This involves a collection of the largest possible number of existing malaria survey data from articles published in scientific journals, university

theses, ministry reports and unpublished work by research institutions. The type of data that are being collected (essentially parasite ratio but also other data when available) are described in the next section. In most countries routinely collected disease reports were not used because they are too incomplete. The compilation of these "empirical data" will lead to the creation of a Pan-African database which will be made public and which will provide the basis for risk mapping down to the second administrative level ("district").

For the data collection process, Africa was divided into functional regions, with five regional centres and two sub-centres responsible for 5-7 countries in their region (Figure 1). The regional centres are located at existing institutions throughout the continent (see list on the inside of the cover), each with a full-time data co-ordinator supervised by a co-investigator. Since it was necessary to geo-reference all collected data, the data co-ordinators were trained in the use of GIS and equipped with the necessary hardware, software and digital data sets. Although the MARA/ARMA activities are located at certain institutions, the initiative itself is non-institutional and runs in the spirit of an open collaboration involving countries and people within Africa who want to participate and contribute.

In addition to the malaria data, data on vectors and on epidemic highland malaria were also collected in the frame of closely related initiatives.

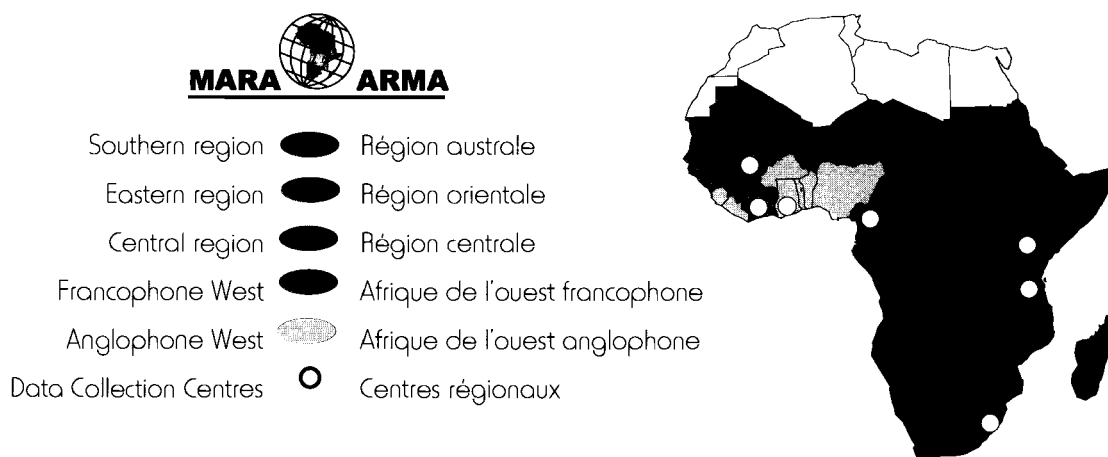
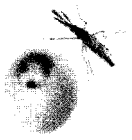


Figure 1. Functional regions and data collection centres in the MARA/ARMA collaborative project. Data collection centres are located in Bamako, Bouaké, Dar es Salaam, Durban, Nairobi, Navrongo and Yaoundé.



B Modelling

This focus involves predictive modelling on the basis of climatic and other environmental factors, in order to supplement the data collection of empirical data in areas where no such data exist. A model of malaria distribution has been derived from available rainfall and temperature data (resolution: 5 x 5 km) for the whole continent. Further modelling is addressing issues of malaria seasonality, the frequency of epidemics in fringe areas, and, at a smaller scale, a description of malaria endemicity and levels of transmission intensity, based on both empirical and environmental data.

The main rationale behind the modelling was: (1) malaria data is distributed unevenly both within and between countries, and (2) the data points on their own are not sufficient to complete the picture of malaria endemicity for various reasons, which are discussed in Chapter 3. We need both the point malaria data as well as the continuous coverages of environmental factors which affect malaria transmission, and then we need to extrapolate, using spatial models, to complete the picture.

The factors that determine the distribution and severity of malaria are diverse and complex, but climate can be considered the major determinant. Temperature and rainfall limit malaria to the warm, humid regions of Africa, where the mosquitoes and parasites can breed and develop, and transmission can occur. Such climate data are increasingly available in the form of data surfaces that can be manipulated in a GIS and can be used to make predictions about data-poor areas. Both approaches - the data collection and the modelling - are run in parallel and the empirical data have already been used to develop and validate environmental models of endemicity in a number of countries.

Products

The targeted users of the MARA/ARMA collaboration will include the malaria control programme managers at national and local level.

The trend in recent years in Africa has been the decentralisation of health systems down to the second administrative level ("district"), and this atlas should assist at all levels. The wide dissemination of MARA/ARMA products is therefore very important.

Products will be presented in more detail in the following chapters. They include an atlas of malaria risk in Africa, poster-size maps, books and pamphlets, digital maps and malaria databases on CD and the Internet, as well as publications in scientific journals. Training in both GIS and the use of malaria data has been an important component of the collaboration from the start and this will be further strengthened during the next phase, with support from the Multilateral Initiative on Malaria (MIM).

Objectives

In view of the above, the objectives of the MARA/ARMA collaboration can be defined as:

1. To carry out a comprehensive collection of available malaria data for the African continent;
2. To highlight areas of no or sparse data;
3. To spatially define factors which exclude malaria (eg. absence of population, high altitude, deserts) in order to delineate zones where malaria transmission is unlikely to occur;
4. To define malaria risk categories in terms of climatic and environmental data and to develop models able to predict malaria risk over the whole continent;
5. To map areas at risk of epidemic malaria;
6. To develop a base-map of malaria risk in Africa, at the level of second administrative unit ("district") which integrate geographic, population and environmental factors;
7. To make continental and national risk maps available to national, regional and international organisations;



8. To contribute to the training of malaria control staff in the areas of GIS with a view to using it in evidence-based health planning.

Chapter 2

Focus A - Empirical Data Collection

What Data?

Disease Incidence

Disease incidence and mortality rates are the preferred data of the MARA/ARMA collaboration since such rates describe directly the disease risk for a given area. Unfortunately, many countries in Africa do not have reliable disease surveillance systems so that routine disease statistics can not be used (World Health Organization, 1994). As a result there is a need for collecting other types of data ("proxy indicators") to describe malaria endemicity.

There are exceptions to this and routine data from countries such as Namibia, Botswana, Zimbabwe and South Africa have been used. Malaria incidence data collected in the frame of special surveys - for example in the frame of an intervention trial - have also been included into the MARA/ARMA database.

Entomological Inoculation Rate

Entomological inoculation rates (EIRs) describe the number of infectious bites an individual is exposed to in a given time period (typically a year). This allows a direct estimation of transmission which is easy to understand and to compare. In theory the EIR is one of the best ways to define malaria endemicity. Unfortunately, measuring of the EIR is beset with problems. Firstly, the methods that are used are insufficiently standardized so that EIR estimates may differ widely depending on the sampling tools used. Secondly, sampling errors can be great in areas where mosquitoes are rare and/or rarely infected, and this applies especially to areas with low transmission. Finally, high-quality long-term

surveillance studies are rare and EIRs are therefore not available for many settings.

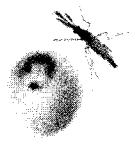
Parasite Prevalence (Parasite Ratio)

Parasite prevalence surveys have been done frequently in Africa and parasite ratio (PR- the percentage of subjects found with a positive blood slide) data are common. In addition, such cross-sectional surveys are not subject to many methodological errors, although quality of microscopy may vary. PR do not provide a direct quantitative estimate of new infections unless the survey is restricted to infants, in which case the age-related acquisition of parasitaemia gives a direct measure of transmission (Macdonald, 1957). Never-the-less, PR relate to the intensity of transmission and they have therefore been used to define endemicity in classical malaria epidemiology.

Malaria is described as endemic when there is a measurable incidence both of cases and of natural transmission over a succession of years. The most widely cited method to describe levels of endemicity was based on spleen rates and was proposed during the malaria conference in Kampala in 1950 (WHO, 1951). Subsequently the definition was revised, based on PR (Metselaar and Van Theil, 1959):

- Hypoendemic: PR in 2-9 year olds \leq 10%
- Mesoendemic: PR in 2-9 year olds 11 to 50%
- Hyperendemic: PR in 2-9 year olds constantly $>$ 50%
- Holoendemic: PR in infants constantly $>$ 75%

Although widely used this classification creates artificial groups from a natural continuum and hides important differences between localities.



Several other attempts have been made to classify endemicity (Gill, 1938; Lysenko and Semashko, 1968). This has involved the definition of malaria "paradigms" based on parasite and vectors species, level of transmission, population, social, behavioural and economic characteristics, health infrastructure, use of drugs, influence of development projects, climate and geography. The categories were derived so as to create a malaria classification that would fit with available intervention tools. Unfortunately most of the required information is not available widely in Africa.

In the frame of the MARARMA collaboration we have decided to use PR as the main malaria indicator because of its wide availability and reliability. Validation against other indicators (such as EIR and available incidence data) may lead to a re-definition of the classical endemicity cut-offs.

The age categories used by Metselaar & Van Thiel (1959), i.e. 2-9 years for all categories except for holoendemic areas, may be meaningful, but they remain arbitrary. Omumbo *et al.* (1997) investigated whether it mattered which age category was used to calculate endemicity. Even though the PRs varied between different age categories, (the difference between the 1-5 and the 6-9 year categories was most pronounced), only rarely (8% of the time) did they fall in different classes of endemicity. On the basis of these results it was decided to concentrate on PRs in children below 10 years, excluding infants, irrespective of the age groupings each survey used.

Other effects on PR needed to be considered: for example the effects of season, which often causes dramatic differences between wet season PR and dry season PR. In addition to the within-year variability there also exists clear inter-annual and longer-term variability in many parts of Africa. To keep track of this, information on date and season needed to be recorded, as well as any other information about prevailing conditions at the time of the survey.

Differences in PR over small distances have been well described in a number of settings (Cattani *et al.*, 1986; Jambulingham *et al.*, 1991; Sharp and leSueur, 1996; Smith *et al.*, 1995). They are dependent not only on random chance distributions of infections, but also on systematic variability such as distances from breeding sites, human behaviour, type of housing and many more. This kind of information is only rarely recorded, and MARARMA operates at a level where such small area variation is not accounted for, but forms part of the "background noise", that may partially obscure larger-scale relationships with environment. Nevertheless, information on the presence of swamps, irrigation or rice cultivation was recorded if given in the report.

Survey types and sampling method have also been considered, since fever surveys and clinic based surveys tend to over-estimate the community infection prevalence. School surveys, which inevitably only include children well enough to attend school, and often include older children in which immunity may reduce infections, tend to under-estimate the PR. The ideal survey design was therefore based on a true random sampling of children to reflect the geographic and age-distribution of a well defined community.

It was not known how much data would be found, so no exclusions were made on any of the above criteria at the collection stage, but all details were recorded so that quality-coding of the data would be possible at a later stage. The diagrammatic model of the MARARMA data base (Figure 2) shows all information that is being collected, if reported.

Historical Malaria Maps

Apart from actual reports of malaria surveys, historical distribution maps drawn and/or used by national authorities were also collected. The contents, origin and quality vary, but give a good indication of the perceived or measured malaria situation in these countries. These maps are being digitized (converted to computer maps) and are a useful resource.

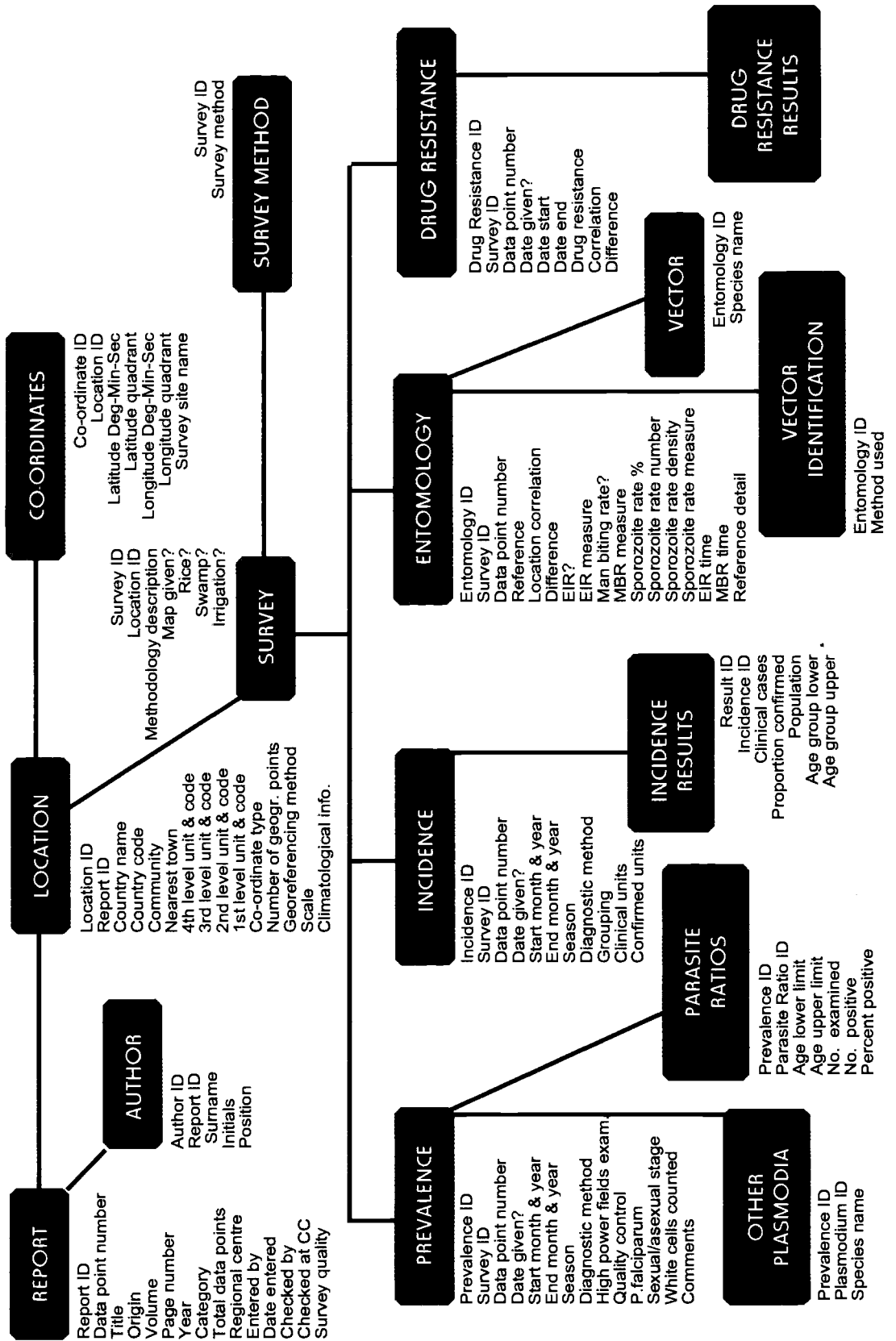


Figure 2. MARA/ARMA database model showing all the different data that is being collected and the relational linkages.



Data Collection

How Are the Data Collected?

The format of the malaria data to be collected was largely unknown at the onset of our work, so a collection system had to be designed that would standardise data collection across the continent, but would still be flexible enough to allow for unknown possibilities.

A data proforma was used for capturing the information in the original reports. It consists of different sections which can be assembled in different ways to cater for incorporation of different types and quantities of malaria data, depending on the reference source. This allows for different types of surveys, undertaken in different geographic locations, at different times to be transcribed to one standard proforma. Operating procedures guide the data collectors through the process of extracting data from reports and publications.

A relational database (Figure 2) was then designed in Microsoft Access™ to accommodate the full complexity of all data relationships. The structure permits future growth, incorporation of new data entities, and a completely flexible means of combining selected data for analysis. To this effect, a stand-alone application conforming to the proforma was created in MSAccess / VisualBasic™ to ensure standardisation. A certain amount of data validation is performed automatically at the point of entry by the system. Verification and further validation is completed at the Durban co-

ordinating centre and queries forwarded to the data coordinators.

Geo-referencing the Data

The survey data had to be "geo-referenced" (i.e. their latitude and longitude determined) for use in a GIS. In some reports the longitude and latitude of the survey site are published, others give only the name of the area or settlement where the survey was carried out. In this case the

geographical location had to be obtained by either reading it off a topographical map, or by using digital maps and databases, such as the African Data Sampler (World Resources Institute, 1995) the Geoname Gazetteer (GDE Systems Inc., 1995) or Encarta (Microsoft, 1998) (See Appendix).

Search Strategy and Data Sources

The data searching strategy relied on multiple channels in order to ensure the best possible completeness of data. Firstly a complete literature search was done using the bibliographic databases Medline and Embase. In this way the majority of published data for Africa was identified. The reference sections of the identified publications were then screened to identify additional publications. All journals (national or international) likely to contain malaria data were also hand searched at the support centre in Switzerland and at the East African regional centre. A total of 30 international and continental journals and 28 national journals were hand searched for the period 1960-1997. Some data points have been obtained by contacting researchers and authors known to have worked in a particular region.

Secondly, because unpublished data is rarely in a format that allows it simply to be mailed, a personal visit by the data coordinator was needed to get access to this source of information. The regional data coordinators started to visit all identified institutions likely to hold unpublished documents in the countries under their control. This included the relevant ministries, universities and research institutions. This long-term work, which is very cost- and time intensive, is still ongoing.

Finally, international archives in Africa and in Europe (WHO Geneva, Paris, Antwerpen, Lissabon) are being searched and all identified documents abstracted. As of mid-1998, this intensive search has allowed to identify 1014 individual reports / data sources. Of these, 29% were from scientific journals, 45.5% were Ministry of Health reports, 19.5% were other reports from international bi-or multilateral agencies,



NGOs, mission hospitals or personal communication and 5.9% were found in postgraduate theses (Figure 3). The large amount of data from unpublished sources confirms the need for country visits to locate unpublished records.

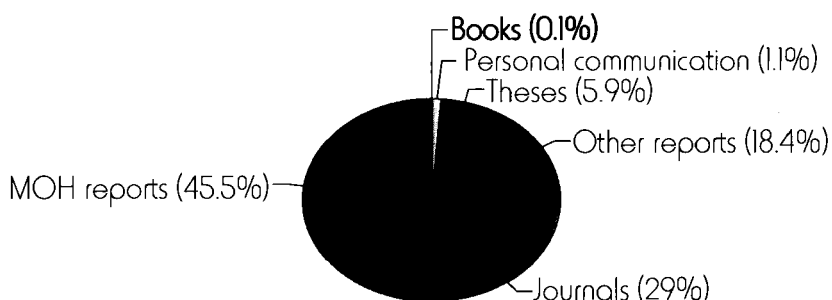


Figure 3. Sources of data collected by MARA/ARMA. One data source (or "report") may contain many data points or several individual surveys.

From these various data sources, 2529 prevalence ratios conducted on children under 10 years of age between 1926 and 1997, 147 records of malaria incidence and 52 entomological inoculation rates were extracted. A map of all survey points collected to date is shown in Figure 4. One report may contain several data

points, one data point being one set of results unique in source, space and time, but may still be broken down into different age categories. The abundance of collected surveys is remarkable, considering the logistic constraints in the collection process. So far some countries have been well

covered, while in others data is very sparse or difficult to access. Once the collection process is completed, remaining data gaps will need to be filled by modelling malaria risk on the basis of other data-rich regions where conditions are similar.

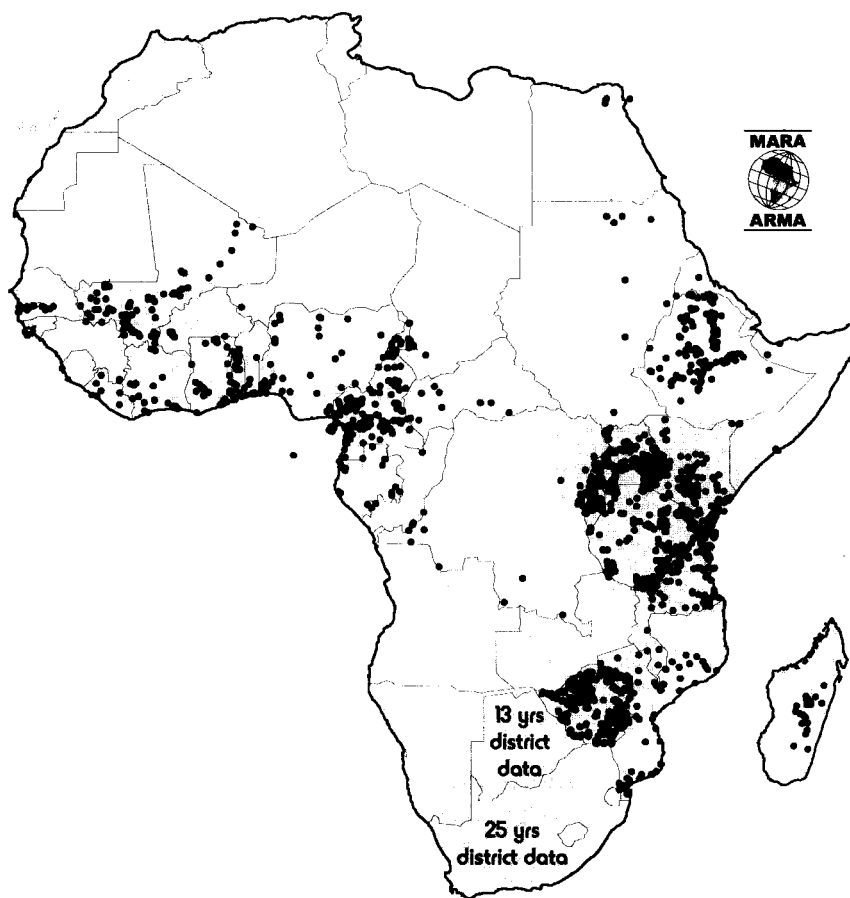


Figure 4. Data points collected to date (July 1998) across the continent. A data point is one set of survey results unique in time, locality, source and method.



Chapter 3

Focus B - Modelling

Modelling: Why?

Why do we need models if we are collecting empirical data? Firstly, the data is not evenly distributed. Some countries have an abundance of malaria data, while in others data are very sparse or difficult to come by. Within countries, data points are often concentrated where researchers have been active, where malaria is known to be prevalent or during epidemic years. In countries in which hundreds of reports were found, large areas remain unexplored (Omumbo *et al.*, 1997). Secondly, parasite ratios on their own do not necessarily give a clear picture of malaria endemicity. Small-scale factors that cause

local differences in PRs, can be misleading and are not always important for control activities. Surveys carried out during malaria epidemics do not give a realistic view of those areas in non-epidemic years. These issues are illustrated in Figure 5: the PRs (circles are small for low PR, large for high PR) in two different countries may be distributed as in (a), while the actual underlying malaria status may look like as in (b). It would not have been possible to get a complete picture from the PR data alone. This "filling-in-the-blanks" involves different kinds of modelling.

Modelling: What?

There are many questions one can ask about malaria in Africa. The first and most basic question is "Where does malaria occur - regularly / occasionally / never?". This concerns the *distribution* of the disease, and what happens at the *periphery* in terms of *epidemics*. One can ask "How many people carry, get sick or die of malaria?" and "What is the risk of contracting malaria?". These questions relate to issues of *transmission intensity* and its effect on human *health*. One can ask "When and for how long is malaria transmitted?", and here we are concerned with the *seasonality* of malaria transmission.

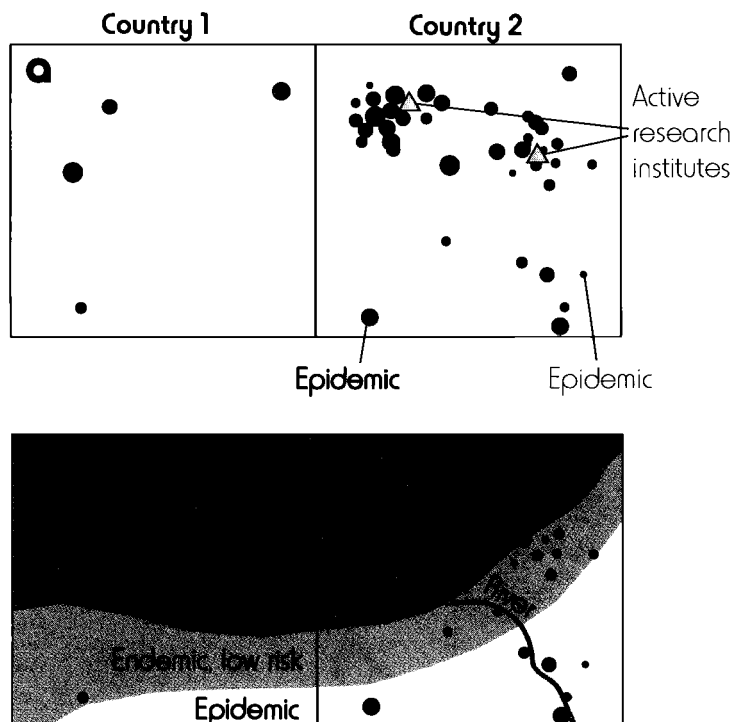


Figure 5. The need for geographical modelling is illustrated in these hypothetical examples: (a) malaria surveys are unevenly distributed within and between two bordering countries for various reasons; the point size reflects prevalence; (b) the actual malaria endemicity can not be derived for the whole area from the available parasite ratios alone. The effect of environmental gradients (elevation contours) and features (large rivers), as well as the effect of epidemics and low-level variability on parasite ratios is illustrated.

Modelling: How?

These questions can then be dealt with at different levels. The factors important at continental level differ from those that play a role at regional or local scale. We view



the modelling of malaria in Africa as a four-level approach:

- (1) The first level, at the continental scale, defines the broad distribution of transmission and disease, based on climatic conditions in an average year;
- (2) the second level, at a sub-continental scale, refines the distribution at the periphery by taking into account inter-annual changes in climate and differences between major ecological zones;
- (3) the third level, at a regional or national scale, uses a combination of empirical and environmental data to define transmission intensity within a country or a zone of transmission ecology (such as perennial, seasonal or bi-seasonal transmission); and
- (4) the fourth level, at a scale of 30 km² and below, operates below the second administrative unit and investigates variation in transmission on a very localised scale.

What Do We Know?

Malaria is governed by a large number of environmental factors, which affect the distribution, transmission intensity, disease outcome, small-scale variation and seasonality. Different factors come into effect at different spatial scales - some at the continental scale and others at a very small scale, such as between villages. Any modelling of malaria is limited by the available data, its spacial resolution and whether the relationships between the data and malaria are known or can be measured.

A major factor in malaria transmission is temperature. It affects the transmission cycle in many different ways, but the effects on the duration of the sporogonic cycle of the parasite (n) and vector survival (ρ) are particularly important. The relationships are illustrated in Figure 6a and b. The lower temperature limit of transmission, is determined by the proportion of mosquitoes surviving the parasite's incubation period (ρ^n , Figure 6c). Very low temperatures limit the vector: *A. gambiae*, for example only exist in frost-free

regions (de Meillon, 1934), or where absolute minimum temperatures in winter remain above 5°C (Leeson, 1931).

Rainfall provides mosquito breeding sites and increases humidity, which enhances mosquito survival, and the relationship between mosquito

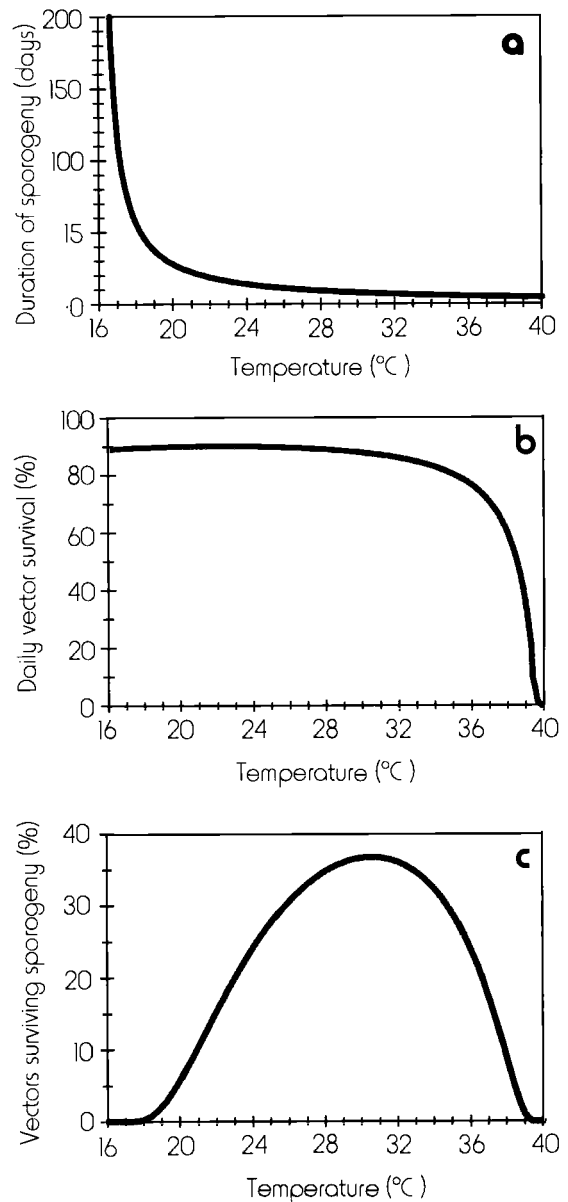


Figure 6. The effect of temperature on malaria transmission: (a) duration of the sporogonic cycle ' n ' in days (Macdonald, 1957; Detinova, 1962) the higher the temperature the shorter the cycle; (b) daily mosquito survival ' ρ ' as defined by Martens (Martens, 1997), (c) the percentage of mosquitoes that survive after the full period required for completion of sporogony ' ρ^n '.



abundance and rainfall has been illustrated repeatedly. Unfortunately the relationship is not direct: a specific amount of rain does not lead to a specific mosquito density. By examining rainfall patterns in known malaria and non-malarious areas, it appeared that an average of 80mm per month, for at least three to five months, was a reasonable requirement for annual malaria transmission (Craig et al, 1998).

Malaria Distribution Model

(Continental level)

“Where Does Malaria Occur Regularly?”

Perhaps the most fundamental question is distinguishing malarious from non-malarious areas. A great many factors affect malaria transmission, but at the continental level the limiting factors are climatic. These control the development of both parasites and mosquitoes and also mosquito survival. Together they determine whether transmission is likely to occur or not.

Recently spatial temperature and rainfall data surfaces for Africa, at a resolution of about 5km², have become available (Hutchinson *et al.*, 1995). These consist of extrapolations from weather station data (from over 60 years) and elevation data, and are suitable for modelling the long term presence or absence of malaria.

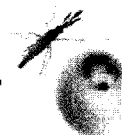
Defining Malaria Distribution

Clearly there are no distinct boundaries dividing malarious from non-malarious regions. Both long-term and annual variation in climate will shift the limits of distribution over time. In addition, climatic factors occur as spatial gradients, and thus the occurrence of transmission cannot be defined by using clear cut-offs. Fuzzy logic (Zadeh, 1965) can solve the problem of using distinct cut-offs, by allowing us to describe the situation in terms of partial truth, or the extent to which a statement is true. It can be used to describe how suitable prevailing climate is for malaria transmission, and how certain we are that transmission can take place.

Going by what is known about the relationships (Figure 6) one can set limits, above which we are sure that transmission can take place, and another limit, below which transmission is more or less impossible. In this way one is expressing the suitability of climate for malaria transmission, and defining the areas where malaria transmission can be expected to occur.

Parasite development ceases at 16°C, but transmission below 18°C is unlikely because very few adult mosquitoes survive the 56 days required for sporogony at that temperature, and because mosquito abundance is limited by long larval duration. At 22°C sporogony is completed in less than three weeks and mosquito survival is certainly great enough (15%) for the transmission cycle to be completed. Thus temperature below 18°C was considered unsuitable, and above 22°C, suitable for stable transmission. The upper limit of temperature suitability is determined by vector survival, since sporogony takes less than a week. Temperatures of above 32°C have been reported to cause high vector population turnover, weak individuals and high mortality (D. leSueur, PhD Thesis, University of Natal, 1991; R. Maharaj, PhD Thesis, University of Natal, 1995), and thermal death occurs at 40°C. In terms of rainfall, 80mm per month was considered suitable, 0mm unsuitable.

The climate data maps were assigned new, fuzzy, values, based on their suitability for sporogonic development and the occurrence of rainfall, which indicate how suitable (on a scale of 0 to 1) the climate is. Since both temperature and rainfall have to be favourable at the same time of the year to allow transmission, the suitability maps were combined to calculate which of the two was more limiting each month. Furthermore, suitable conditions have to continue for a certain time period, long enough for the transmission cycle to be completed. In the hot north African countries the rainfall season only needs to last for three months for mosquito populations to grow enough to permit transmission, while in the rest of Africa the required period was set at five months. Finally, all areas with frost in winter were masked from the distribution model because frost eliminates



mosquitoes populations. The details are given in Craig *et al.* (1998).

Because the climate data are a long-term mean, one is calculating climatic suitability in the *average* year, and thus the suitability for *stable*, or annual, transmission.

What Does the Model Show?

The resulting model (Figure 7) shows which regions are suitable (1) and which are unsuitable (0) for stable malaria transmission. A value of one

means that malaria transmission is most likely stable; zero means transmission is very unstable, with possible but rare epidemics, or altogether absent. In-between (values 0.9 to 0.1) is a gradient from stable to increasingly unstable transmission, with decreasing levels of transmission, until, at the outermost fringes, malaria becomes sporadic and unpredictable. All suitable areas (value 1) may still vary from low to high transmission intensity, which is not discriminated in this model.

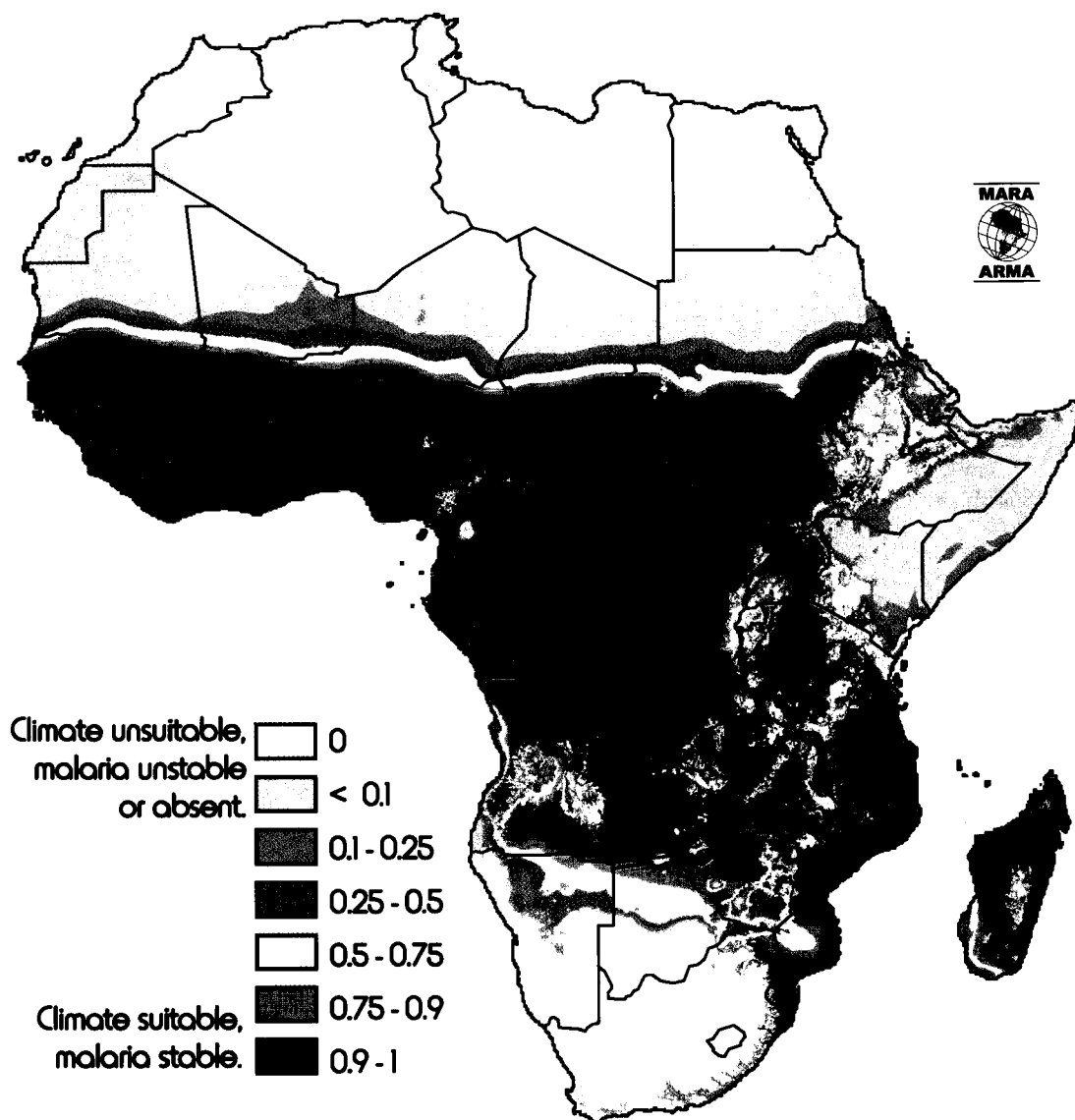


Figure 7. Climatic suitability for stable malaria transmission, where 0 = unsuitable, hence transmission very unstable or absent, 1 = highly suitable, hence transmission stable, and fractions between 1 and 0 = decreasing suitability, therefore more and more unstable transmission.



Figure 8. Comparison of the model with southern African malaria maps: (a) the climatic suitability model; (b) malaria risk map and expert opinion map of malaria risk in 1995 in Namibia, annual confirmed malaria case numbers per district in Botswana from 1982 to 1994, and a malaria risk map of South Africa drawn up by the Department of Public Health in 1938.

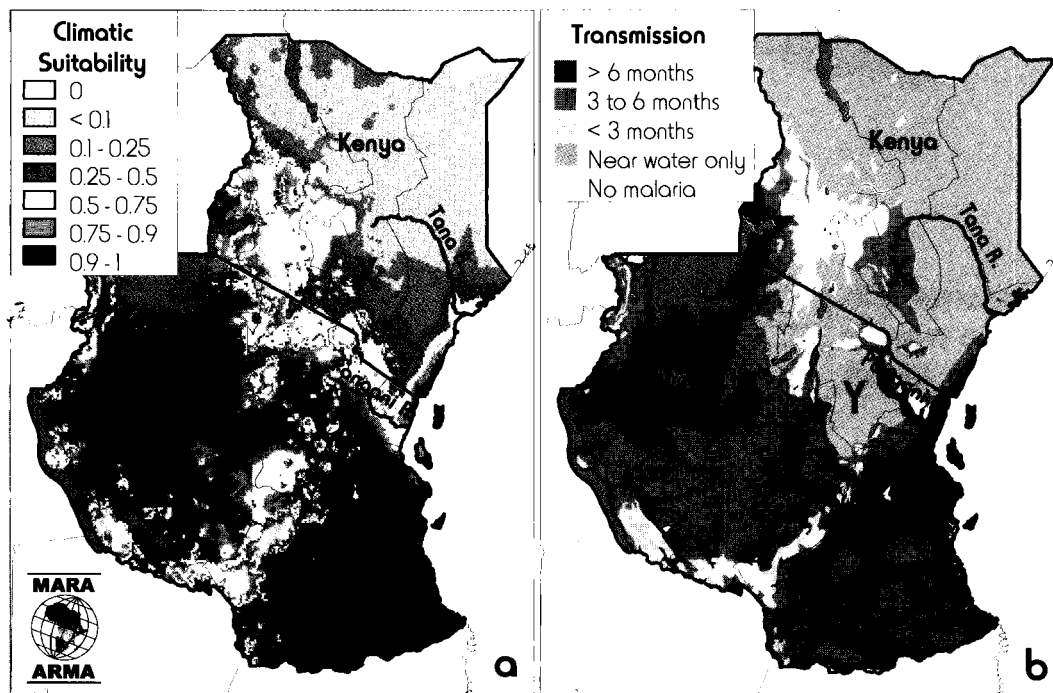
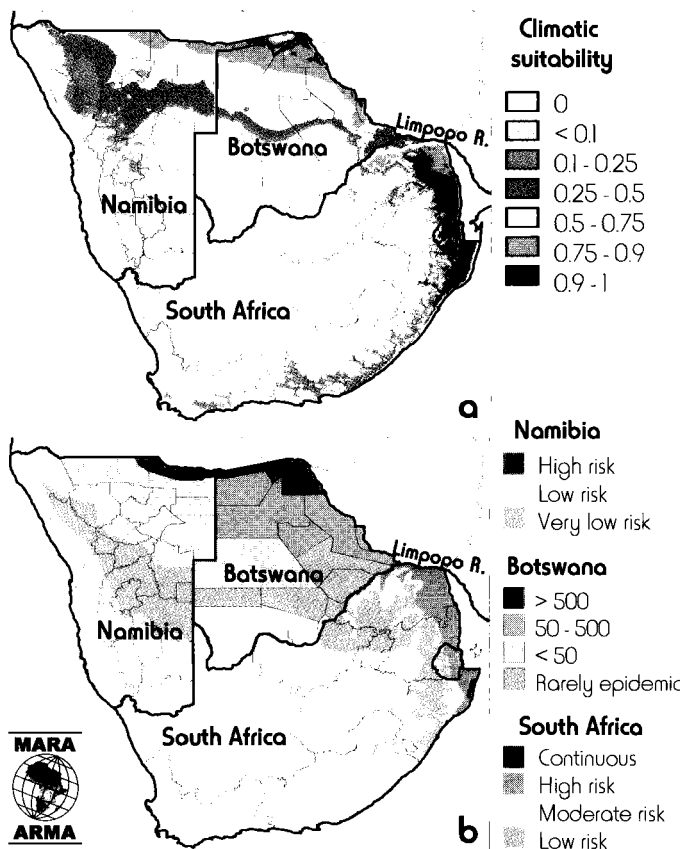
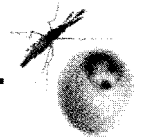


Figure 9. Comparison of the model with Kenyan and Tanzanian malaria maps: (a) the climatic suitability model; (b) historical malaria maps of malaria risk in Kenya (Nelson, 1959) and Tanzania (Wilson, 1956).



Comparing the model with historical maps and malaria case data from southern Africa (Figure 8), Kenya and Tanzania (Figure 9) the resemblance is striking. The discrepancies in the major river valleys result because the model uses only rainfall to predict water availability, while mosquitoes do survive along major river banks and flood plains. Other differences (regions X and Y in Figure 9) are less easy to explain. Region X is flat, low-lying country, with a high vegetation index that indicates an abundance of water. However, empirical data from this region suggest that malaria transmission is low and variable, and we have to question the accuracy of the historic map. Region Y was probably

recorded as low risk historically, because there were no people living in the area. These examples illustrate the need for future checking and refining of models and data.

Estimating Populations At Risk

The distribution model (Figure 7) has been used to estimate the populations at risk of malaria, by overlaying it on a continental population coverage (Deichmann, 1996). This was done by calculating the number of people living in stable transmission areas, where the fuzzy value was greater than 0.5 (Figure 10). Finally, using morbidity and mortality estimates from across the

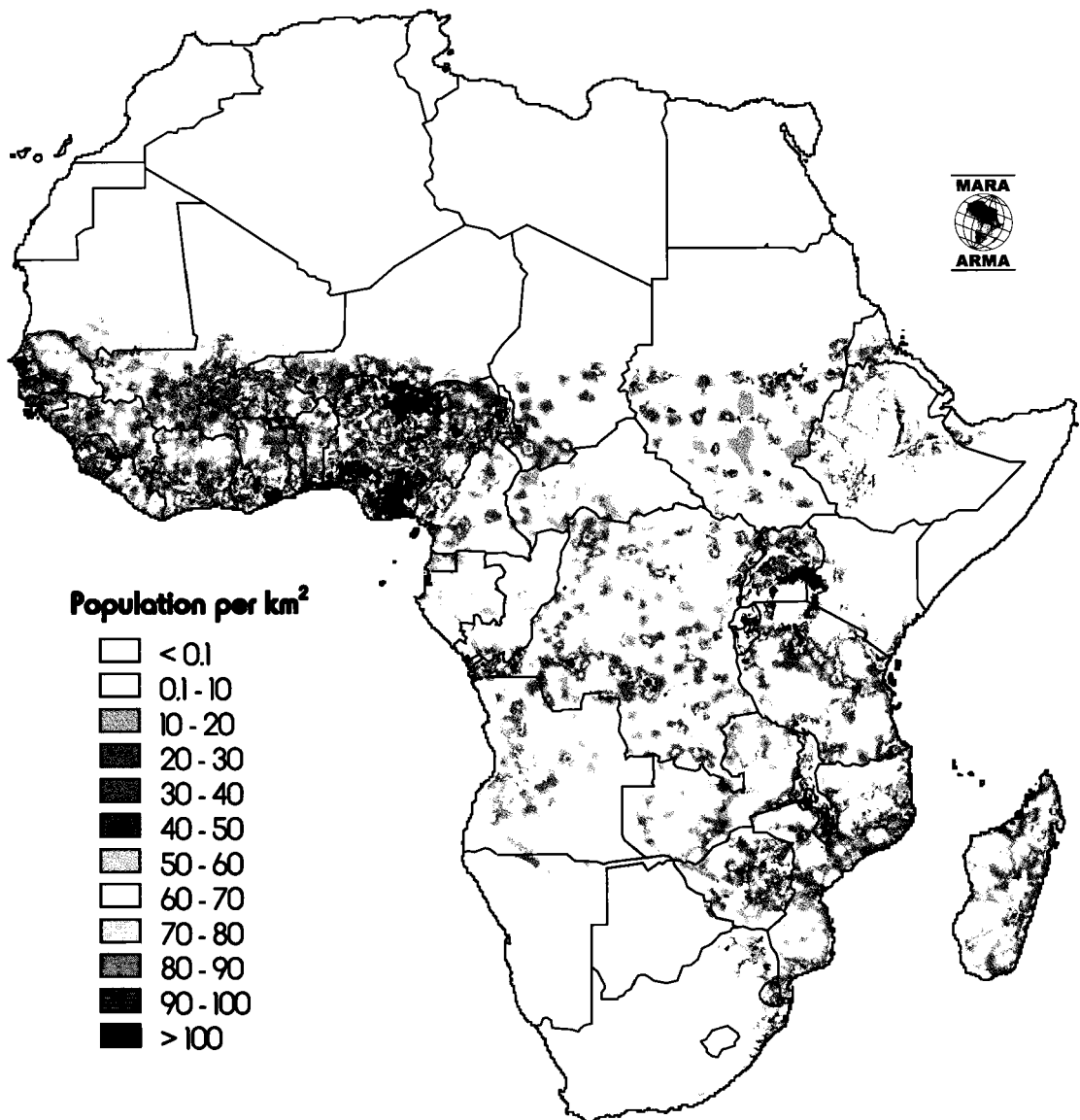


Figure 10. Total population per km² in 1990, where malaria transmission is stable (model value >0.5).



continent, the number of deaths due to malaria (Table 1) was estimated (Snow *et al.*, 1998a). Like the distribution model, this method is still wrought with many unknowns, but it is a new approach to estimating continental burden of disease. Because the process is repeatable and

numerical, the estimates will improve as the model is verified and as more information becomes available about malaria-specific deaths and short-term and long-term health effects, as well as indirect effects of malaria on overall morbidity and mortality.

Table 1 Estimates of total and childhood (0-4 years) populations living in areas 50% and 90% suitable for stable malaria, and consequent estimates of annual malaria deaths among African children for 1990 (Snow, *et al.*, 1998a).

Climatic suitability (Transmission stability)	1990 total population exposed to infection risk	1990 childhood population exposed to mortality risk	Lower mortality estimate: 4.6 per 1000 per year	Median mortality estimate: 8.0 per 1000 per year	Upper mortality estimate: 10.3 per 1000 per year
≥ 50%	360,243,292	66,338,541	305367	530,708	683,286
≥ 90%	293,955,320	54,331,548	249925	434,652	559,615

Seasonality

(Continental Level)

“When Does Malaria Occur?”

Both the duration and the start and end of the malaria season are important to malaria control. The duration of the season will affect the dynamics of transmission with longer seasons allowing more intense transmission and higher levels of infection in the human population. Knowing the duration of the transmission season is important in terms of ensuring that suitable control strategies and tools are used (e.g. in an area with 9 months of transmission, impregnation of nets needs to be carried out just prior to the onset of the season and with an insecticide with a residual effect of at least 9 months). As with distribution, the primary factors determining the onset and termination of transmission are climatic.

In the highly seasonal areas, where the annual rainfall and temperature ranges are great, mosquito populations annually drop to levels where transmission cannot be sustained. As rain sets in and/or temperature rises, the vector populations must recover from their annual out-of-

season lows to levels where transmission can again take place. This requires a period of highly suitable climate, especially if the season lasts only for a few months. On the other hand, where climate is stable all year, mosquito populations do not go through the same marked annual growth and decline cycles, but persist at more stable levels. A slow steady population turnover is possible even at temperatures close to the lower threshold (around 18°C), if these temperatures persist all year. It is therefore understandable that summers in highly seasonal areas need to be hotter than those in stable regions to produce mosquito populations capable of transmitting malaria.

Months of Transmission

The continent was thus divided into two zones: seasonal and stable. Areas were considered to have seasonal climate if annual temperature range was high, or if annual rainfall was less than 720mm. Areas were considered to have a stable climate if temperature variation was low and if annual rainfall exceeded 720mm. The total number of months in which transmission would occur was then calculated by taking into account



two things: (1) transmission does not start immediately on the onset of rain, but usually there is a time lag during which vector populations increase, and (2) rain in previous months has an accumulative effect on the following months (F. Tanser *et al.*, in preparation).

In seasonal zones, monthly temperature and rainfall moving averages had to be 22°C and 60mm respectively to be counted as part of the transmission season, and at least one month of highly suitable conditions (> 22°C and > 80mm)

had to occur. In the stable zones monthly moving averages only had to be 19.5°C for temperature, but 80mm for rainfall, and no highly suitable month had to be present. All months meeting the above conditions were then simply counted to give a map showing the total number of suitable months, i.e. the length of the transmission season (Figure 11).

This also allowed the onset (Figure 12a) and termination (Figure 12b) of the seasons to be calculated. Figure 12 represents the first season in

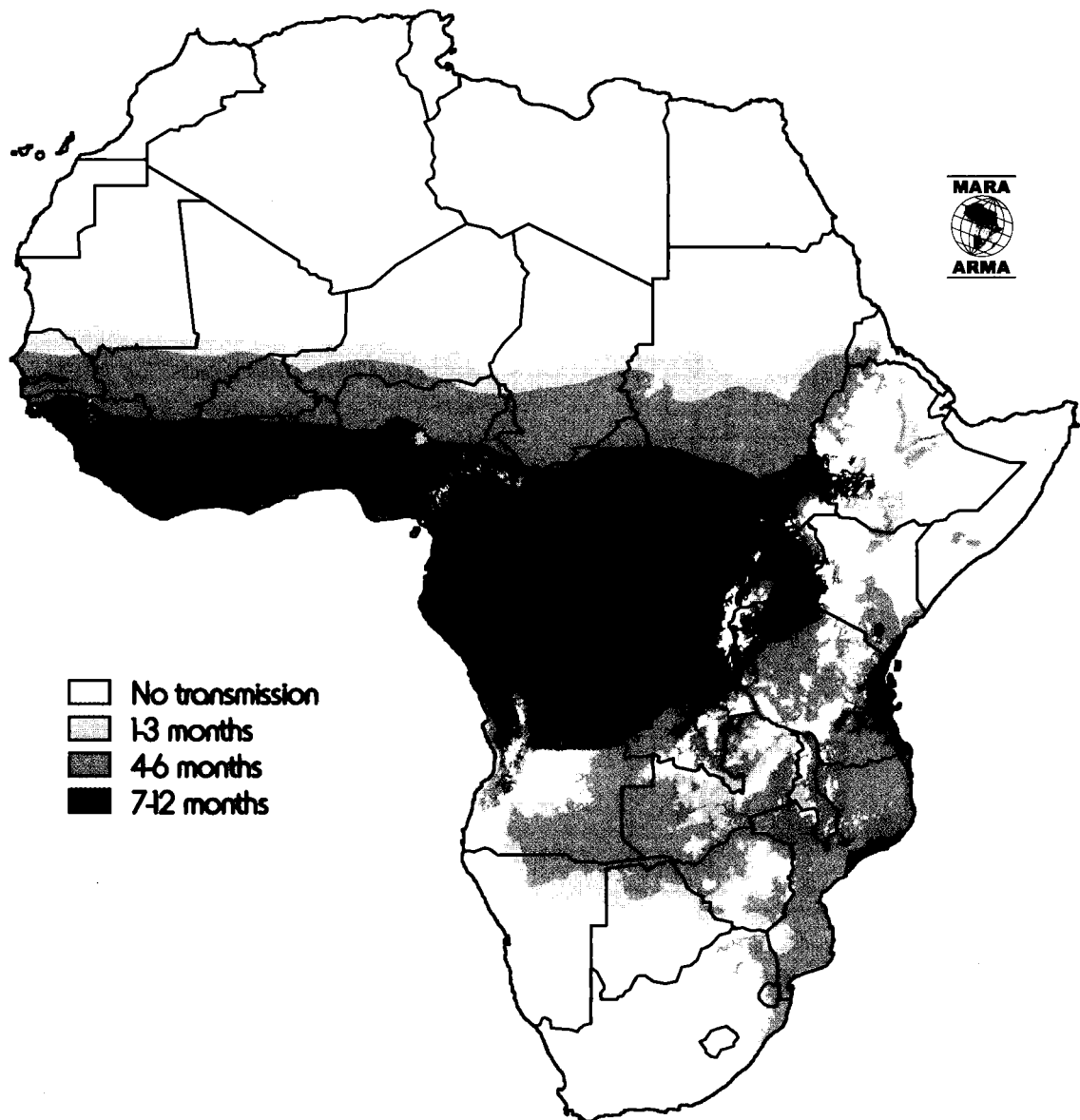


Figure 11. Length of the malaria transmission season. Where the number of months at risk of stable transmission is 1 to 3, malaria is strongly seasonal or epidemic, where it is 4 to 6, malaria is stable but seasonal, where it is 7 to 12, malaria transmission occurs throughout the year. (Model not yet completed for Madagascar).

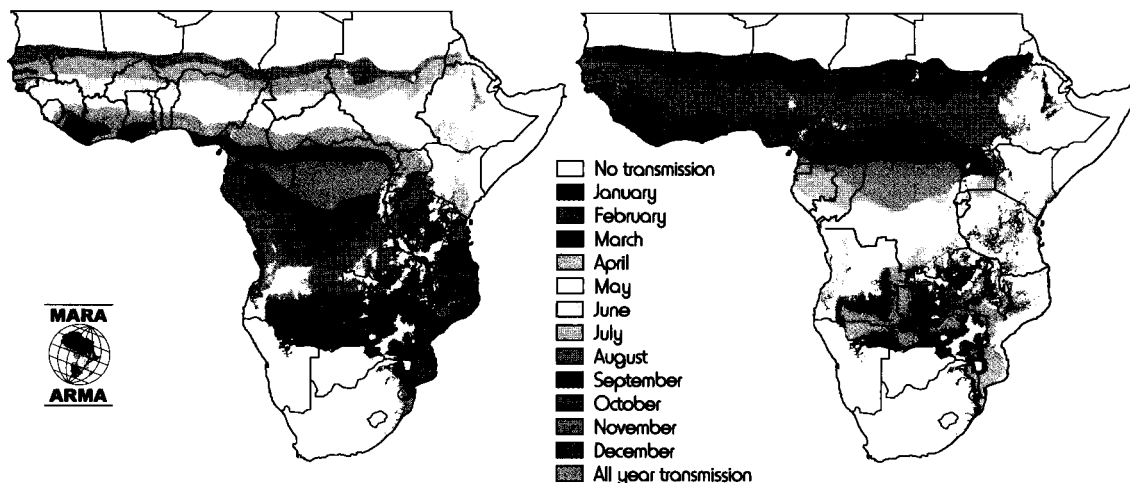
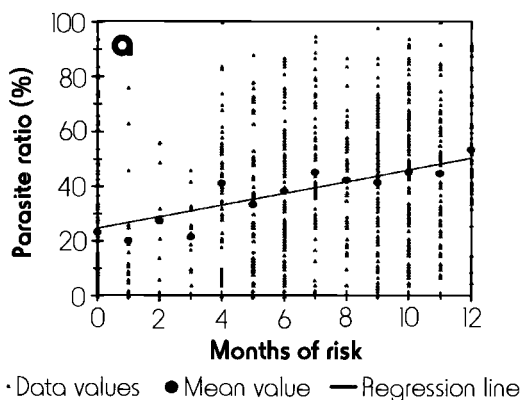
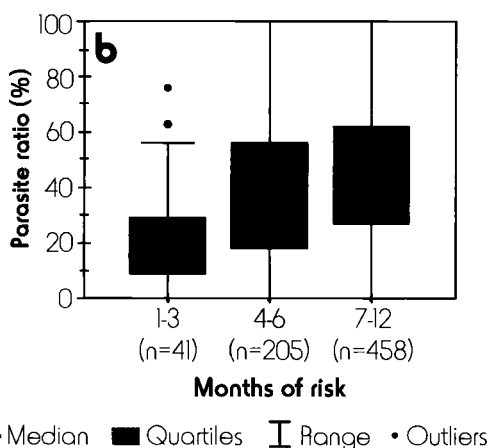


Figure 12. The onset (a) and end month (b) of the malaria transmission season. In regions with two rainy seasons each year, these maps refer to the first season in the year. (Not yet completed for Madagascar).



the year only. A separate map (not published here) was prepared for the second annual season in areas with two distinct seasons to be calculated.



A preliminary investigation was also made between the parasite ratios in the MARA/ARMA database and the number of months at risk. All surveys with a sample size of 50 or greater were selected and the parasite ratios plotted against the number of months of risk. There appeared to be a clear relationship between average PRs and number of months at risk (Figure 13a), but the spread of values in each category was great and as a result statistical correlation was poor. However, when using the three risk categories displayed in Figure 11, the differences between PRs in these categories (Figure 13b) were significant ($P < 0.001$). The process of selection of data points did not take into account the time of the survey, which will be important in peripheral areas of transmission, where the parasite ratio is less stable. Thus the use of months of risk to determine transmission intensity could be refined by treating stable and unstable areas separately and taking into account the time of the survey.

Figure 13. MARA/ARMA malaria data plotted against number of months at risk as calculated in the seasonality model (Figure 11): (a) parasite ratios against number of months at risk ($n = 799$, $r^2 = 0.1$, non-significant); (b) parasite ratios in three categories of season length were significantly different ($p < 0.001$).



Malaria At the Periphery

(Sub-continental Level)

“Where Do Malaria Epidemics Occur?”

The question of epidemic malaria concerns the occasional malaria outbreaks in normally malaria-free regions or, in its wider sense, a particularly severe season in a normally low-risk area. Factors that cause epidemics range from unusually prolonged or favourable climatic conditions, to man-made alterations to the physical environment that allow mosquito breeding where it was not possible before (irrigation, dam or canal

constructions, deforestation) and the movement of people into and from malarious regions.

To explore the impact of inter-annual fluctuations on epidemic occurrence, annual climate surfaces were commissioned from the Climatic Research Unit, Norwich (CRU/SAMRC, 1998). These surfaces can be used to investigate the climate patterns over time. Epidemics will need to be investigated at a sub-continental level, because of major differences between north, equatorial and southern African climate patterns. To start off with, a continental malaria distribution model, based

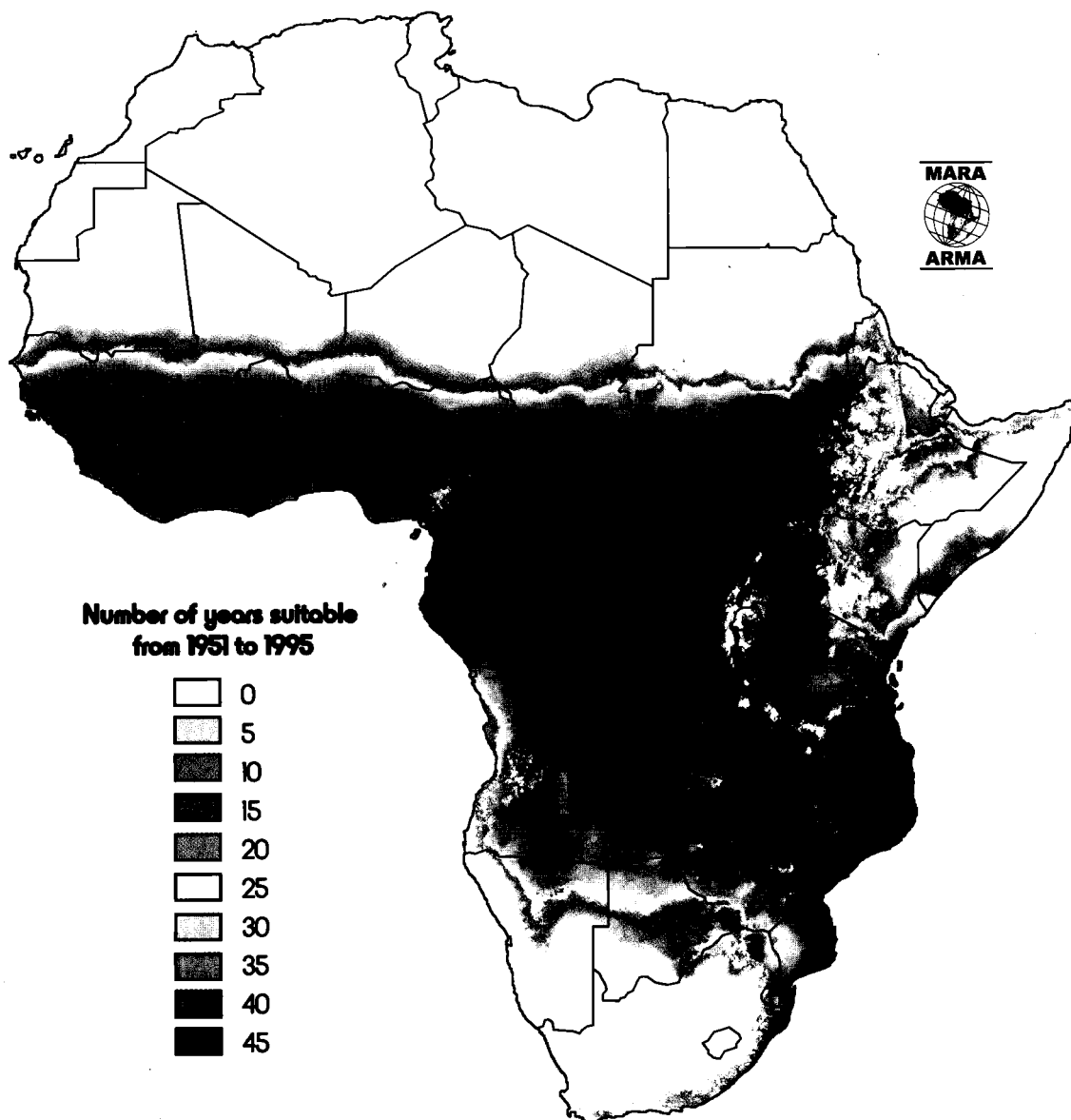


Figure 14. The number of years, from 1951 to 1995, in which climatic suitability for stable transmission was greater than 10% for five consecutive months or more. (Monthly climate data not available for Madagascar).



on a five-month transmission season, was created for each year from 1951 to 1995 (the years for which data was available). The total number of years out of 45, in which climatic suitability according to this model was above 10%, were calculated (Figure 14).

The outcome of this model is in some ways similar to the original distribution model (Figure 7). This is not surprising, because if conditions are *suitable* in the *average* year, transmission can occur *frequently*, but if conditions are *unsuitable* in the *average* year, transmission would occur very *infrequently*, if at all. However, much work still has to be done before we have a useful product that reflects fundamental differences across the continent and that has been tested against records of epidemics.

Statistical Models

(Regional Level)

Extrapolating From Empirical Data

At this level we are looking at malaria in terms of infection rates and how these relate to climatic and environmental factors at a national / regional scale. This level is still too coarse to consider small-scale factors that cause differences in transmission between or within seemingly homogenous zones. At the regional level we are looking for statistical correlations between empirical data and certain environmental patterns, which can then be used to extrapolate to areas for which no data are available. Spatial statistics will play an increasing role in this aspect, but for the moment the models are purely statistical.

Kenya

Despite an unexpectedly large number of published and unpublished survey data, these empirical estimates of endemicity covered only 30% of Kenya's stable transmission regions (Omumbo *et al.*, 1997). Empirical survey data (limited to

124, post 1960, randomly selected samples of more than 100 children aged 1 to 9) were used to develop a climate-based statistical model of transmission intensity. Discriminant analysis determined how well climate and NDVI variables were able to discriminate among three categories of malaria endemicity (high >70%, intermediary 20-70% and low <20%). The model correctly identified 75% (95% confidence limits: 70 - 85%) of the three classes. This model was then applied back to the climate and NDVI data, to predict the malaria endemicity classes for remaining parts of the country where no empirical malaria data was available (Figure 15). The malaria distribution model (Figure 7) was used to mask out all potentially unstable transmission areas (climatic suitability < 0.5).

In the second step this model (Figure 15) was used to estimate malaria mortality and morbidity among Kenyan children. To this end published and unpublished information about mortality and morbidity at different levels of endemicity was extracted and summarized. National population data from 1080 4th level administrative units was available from the 1989 census, and was projected to 1997. The population data was then combined with the information on mortality and morbidity and the endemicity model, to estimate how many children are affected in areas of high,

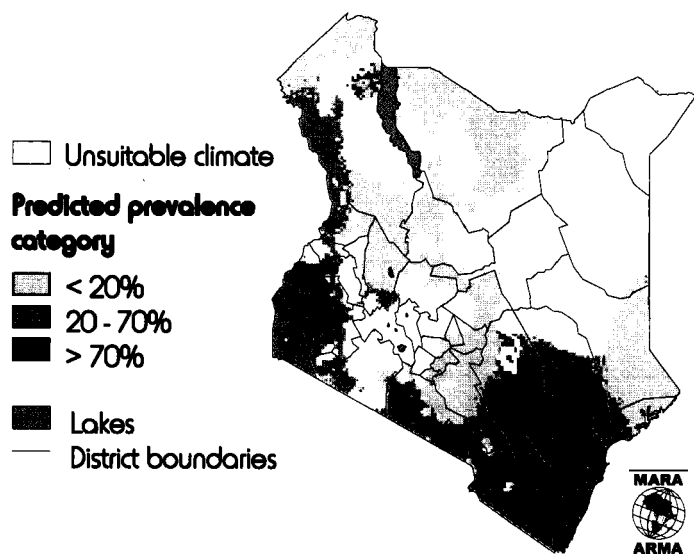
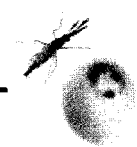


Figure 15. Predicted levels of transmission intensity for Kenya: high (>70%), intermediary (20-70%) and low (<20%).



medium, low or unstable malaria endemicity. In this way it was estimated that daily, 72 and 400 children below the age of five either die or develop clinical malaria respectively (Snow *et al.*, 1998). Despite several limitations, such an approach goes beyond "best guesses" to informed estimates of the geographic burden of malaria and its fatal consequences in Kenya.

Mali

A similar model was produced for Mali (M. Bagayoko *et al.*; I. Kleinschmidt *et al.*, manuscripts in preparation). However, in this case a multivariate logistic regression model was used to find the main predictors of malaria prevalence in children under 10, from among the following factors: temperature and rainfall (Hutchinson *et al.*, 1995), NDVI (FAO, 1991), distance to perennial water bodies (World Resources Institute, 1995) and population density (Deichmann, 1996). The environmental factors significantly associated with parasite ratios were: length of rainy season (number of months with more than 60mm rain), distance to nearest water body, average temperature during the quarter preceding the rainy season, population, and vegetation index during the rainy season.

It was interesting to find that the association between malaria prevalence and distance to water was inverse U-shaped. The highest malaria prevalence was experienced by populations at an intermediate distance from water, and not by those closest to water. This was explained by the fact that people living very close to water make use of bed nets, simply because of the tremendous nuisance of mosquitoes in those places.

The statistical model derived from the data was then applied back to the environmental data surfaces to predict the malaria prevalence for the rest of Mali. Finally, the

predicted malaria risk was converted into one of 4 categories: high (>70%), medium (30-70%), low (10-30%) and very low (<10%), (Figure 16). The prevalence for seventy of the 101 surveys fell within the predicted bands. Further analysis is being carried out on the spatial structure of the data, to see whether there may be other environmental factors that significantly influence the distribution of malaria risk.

Experience From the Regional Models

Both the Kenyan and the Mali regional-scale models produced useful results, that seem to reflect the situation in these countries well. Different statistical methods were used in these two cases: the Kenyan data were first classed into different levels of endemicity, and then analysed to see how well the environmental data could discriminate between the classes. The Mali parasite ratios on the other hand were used directly in a multi-variate analysis against environmental data.

Why were different techniques used? Firstly, it illustrates the explorative nature of the work at the moment. Sample sizes and distribution of

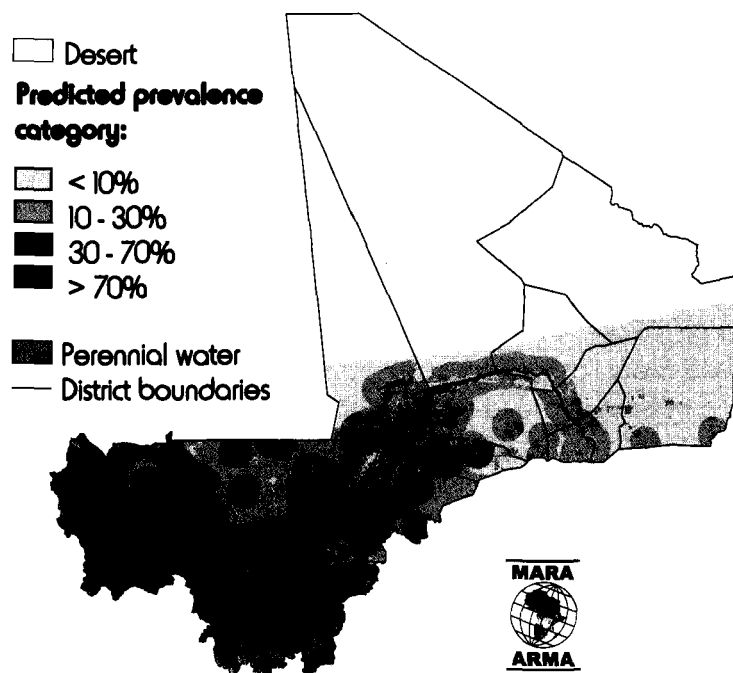


Figure 16. Predicted prevalence rates for Mali: high (>70%), medium (50-70%), low (30-50%) and very low (<10%).



available data affect the choice of the tests to be used. Further, the fact that there are major ecological differences between different parts of the continent, means that the best statistical approach will need to be selected for each region. Kenya and Mali are very different: conditions vary considerably within Kenya, where we find two distinct rainy seasons in some regions and one season or even continuous rain in others, both desert and tropical forests, coastline and very high mountains. Mali on the other hand is fairly uniformly hot, with no high mountains, and with one pronounced rainy season. These differences affect whether or not a variable such as "June rainfall" has the same positive or negative effect on PR in all parts of the country, how it interacts with other variables, such as "June temperature" or "May rainfall" and whether or not it can be combined with another variable, such

as "July rainfall", to reduce the number of variables.

As the data collection nears completion, endemicity models will be created for all malarious countries. We anticipate that different techniques will be applied in different countries or ecological regions, depending on the amount, type and quality of available empirical data, and perhaps also depending on the ecological conditions. During the next stage of the project more effort will be invested into examining and / or developing possibly new statistical and spatial techniques, to deal with the unique problems presented by the MARA/ARMA data set. It is worth noting that in any event the accuracy of the final models will be dependent on and limited by the abundance and accuracy of the data - both malaria data and environmental data.

Chapter 4

Related Projects

Highlands Malaria

Why is Highland Malaria Important?

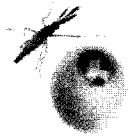
Recently there has been much speculation on the issue of highland malaria in Africa. Highlands have always been regarded as areas of little or no malaria transmission, mainly because of low temperatures. However, this appears to be changing. There is a lot of recent evidence that shows an increase in the number of epidemics in highland areas, as well as a spread of endemic malaria into the highland fringes. Various reasons for this apparent change in epidemiology have been put forward, most prominent are those arguments that implicate climatic and ecological change. Unfortunately the lack of reliable malaria data for most highland areas has made analysis of these issues difficult.

Epidemic malaria in highland areas represents a significant public health problem. Historically, low risk

of infection in highland areas has created little functional immunity in local populations, resulting in relatively high case mortality in adults and children during epidemics. At the same time, national malaria control programmes have not been well equipped to identify and respond to epidemics. There is, therefore, a need for increased scientific understanding of the epidemiology of highland malaria, as well as greater capacity in epidemic surveillance and response. The HIMAL project, which was the product of a TDR workshop on highland malaria in Addis Ababa in 1996, is designed to address these issues.

What is HIMAL?

The project "Epidemiology of Highland Malaria in Africa" (HIMAL) has been funded by TDR and IDRC as part of the MARA/ARMA collaboration. Within the project we have been collecting data on parasite rates, spleen rates and the locations of epidemics to examine recent trends in highland malaria transmission, to delineate areas of malaria risk in



highland areas, and to evaluate the usefulness of the malaria distribution model (Figure 7) as a stratification for this risk of highland malaria. This has involved a series of country visits and coordination with local research institutions and control programmes to obtain as much relevant data as possible. To date over 300 reports have been collated for nine countries (Ethiopia, Kenya, Tanzania, Uganda, Burundi, Rwanda, Cameroun, Zimbabwe and Madagascar) which together have yielded information on parasite rates for over 900 localities.

Initial results from East Africa have indicated that the malaria distribution model (Figure 7) can provide a very good indication for the cut-offs of stable malaria transmission. In addition we have used information on the historical distribution of epidemics to produce epidemic risk maps for individual countries on the basis of altitude (Figure 17). These are exploratory products, but already the indications are that they correspond well with expert opinion offered by in-country

control programme managers and researchers.

After the current work of HIMAL is complete, the project will focus on collecting prospective malaria data through improved surveillance in highland areas. In particular a workshop to be held towards the end of 1998, and which will include local scientists and control programme managers, will address the design of sustainable surveillance systems, that include capacity building in GIS and epidemic early warning.

Vector Data Collection

There are three main insect vectors of malaria parasites in Africa: *Anopheles funestus* and two members of the *Anopheles gambiae* complex: *An. gambiae* and *An. arabiensis*. The other members of *An. gambiae* complex, *An. merus*, *An. melas*, *An. bwambae* and *An. quadriannulatus* species A and B, are either minor vectors of the parasite or not involved in transmission at all. All the species in this complex are virtually identical morphologically and sophisticated techniques are required to identify them correctly.

Distributional data are important because the species do not share the same behavioural characteristics, nor are they equal in their ability to transmit malaria. *An. funestus* and *An. gambiae* s.s. are largely associated with humans and their habitations, preferring to feed on people and rest inside houses. *An. arabiensis*, on the other hand, will feed on humans or cattle, rest indoors or outdoors, and is slightly less efficient at transmitting malaria. As a result, different control strategies are needed to combat different species. For instance, indoor spraying with residual insecticides will be effective against *An. funestus* and *An. gambiae* but only partially effective against *An. arabiensis*.

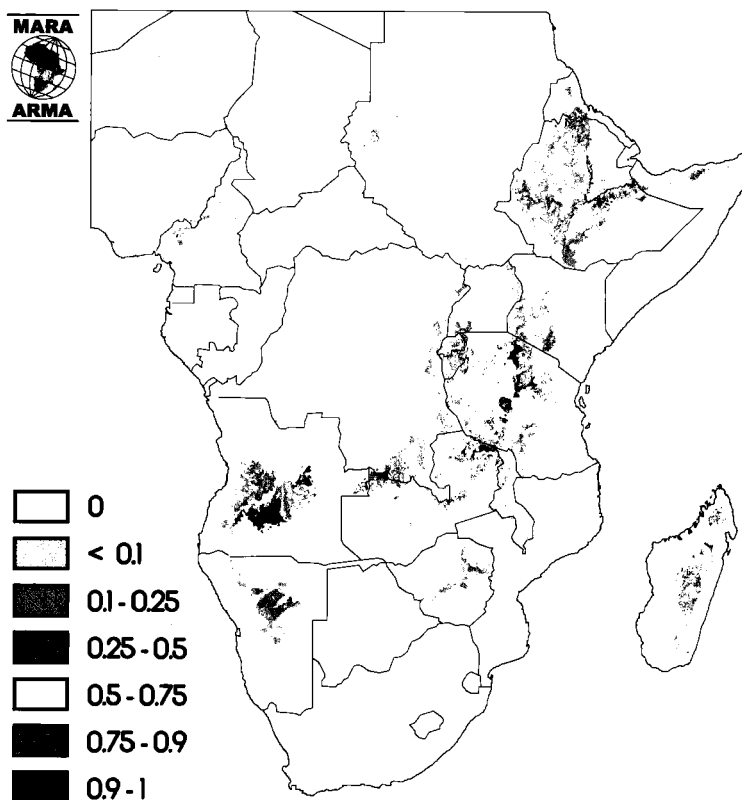


Figure 17. Highland areas (above 1300m) showing climatic suitability for malaria transmission (from Figure 7), therefore showing potential highland malaria areas.

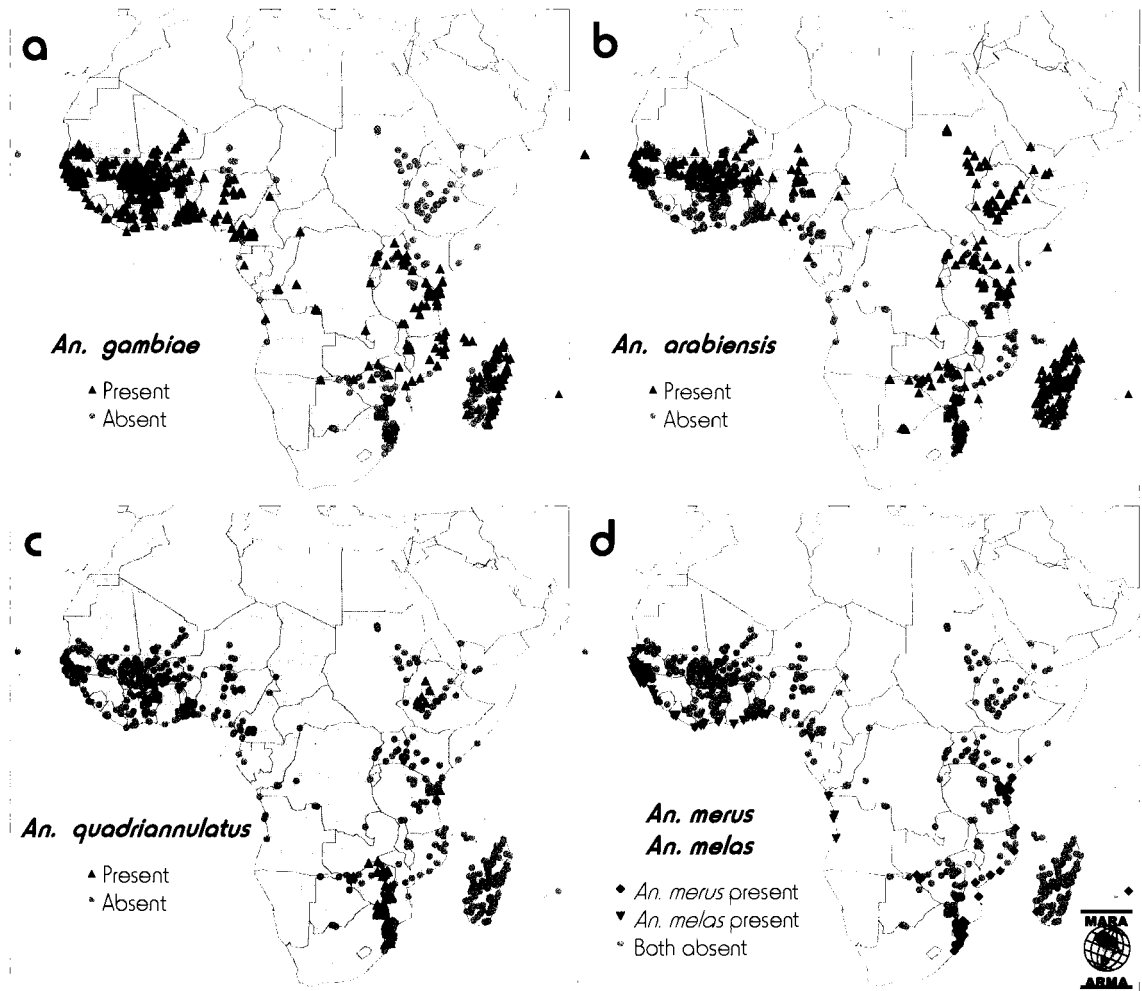


Figure 18. Recorded collections of (a) *An. gambiae* s.s.; (b) *An. arabiensis*; (c) *An. quadriannulatus* and (d) *An. merus* & *melas*.

Maps of the distribution of *An. funestus* and the combined *An. gambiae* complex were produced by Gillies and de Meillon thirty years ago (Gillies and de Meillon, 1968). This source has been updated for the *An. gambiae* complex and Figure 18a-d shows the distribution of the member species. The records are extracted mainly from published literature from

1962 onwards. Earlier records, in which identification of the species are based on salinity tolerance, are also included, as well as identifications based on cross-mating experiments. Blank areas do not mean that mosquitoes are absent, but that no species identifications have been published from those areas.



Chapter 5

Conclusions and Outlook

MARA/ARMA Products for Malaria Control Programme Managers

MARA/ARMA has started to make its products available at national and international level. Poster-size maps of the distribution model (Figure 7) offer national malaria control programme managers, often for the first time, a comprehensive malaria distribution map, and they have already proven to be very attractive and useful in a number of countries. Beyond their obvious benefit for planning activities, the maps also offer a powerful visual stimulus for discussions with community leaders and politicians. In the future these and other national maps will be supplemented with data on the populations living in areas with given levels of risk - wherever possible down to the second administrative level ("district").

At a regional level such distribution maps could help neighbouring countries to discuss and plan their malaria problem, in a coordinated way, in order to optimize resources. Malaria issues along common borders, as for example between South Africa and Mozambique, are likely to become more numerous with the advent of large scale control, especially if control takes place in one country and not in another. The spread of drug resistance or vector resistance to insecticides, and many other practical issues could also be added to regional maps to give a better insight into the problems faced by managers. Finally, at continental level the MARA/ARMA database, maps, and population-at-risk figures should provide a useful planning tool for international agencies, especially in view of the renewed interest in malaria control.

The present technical report aims to give a general overview of the MARA/ARMA activities to-date to a general audience. Our hope is that this will help programme managers and implementers as well as international agencies to get a clearer idea of the possibilities offered by mapping in general and the approaches developed by the MARA/ARMA collaboration in particular. We welcome any inputs

and suggestions regarding the present work as important contributions to the future of this undertaking and we invite you to fill in and send us the questionnaire in this document. We hope that this instrument will prove useful for the needs of the disease control community.

MARA/ARMA Products for Malaria Researchers

Recent work done in the frame of the MARA/ARMA collaboration has allowed to tackle systematically malaria epidemiology at continental level. Some of the work presented in this report outlined the opportunities for research using comprehensive databases and GIS in the study of malaria in Africa. This work is ongoing and more country-level and continental-level work will take place, based on the possibilities offered by the collaboration.

The Way Ahead

The MARA/ARMA collaboration has come a long way by setting up five functional regional centres and a working data collection infrastructure at continental level and by successfully developing a predictive climatic model. The collaboration has demonstrated the feasibility of a trans-disciplinary and trans-national approach to tackle the issue of malaria risk on the continent.

Where is the MARA/ARMA collaboration going from here? Firstly, the data collection will still be continuing for at least two more years until all avenues have been exhausted. Several countries have not yet been visited and some of the collected data have not been abstracted. No data co-ordinator has been employed so far for southern Africa, and this has hindered the data collection in this region. The database is the major resource in this project and the collection process has to take a high priority until its completion.



Secondly, environmental malaria models for the whole continent will be further developed and refined. This should lead to better overall malaria maps. The model could also be a useful start for predicting the possible extension of malaria as a result of global climate changes. At national level, the statistical modelling process started in Kenya and Mali will be extended to other countries and regions. Statistical methods will be revised, and spatial statistics will need to be incorporated in future. This will increase the number of detailed endemicity maps, as well as maps showing where and which populations are at different levels of risk.

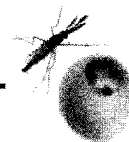
The final product of the MARA/ARMA collaboration will be an atlas of malaria risk for the whole continent,

both in a book version and in digital format, that will contain country maps of endemicity, seasonality, as well as available vector distribution maps. It is envisaged that other related data, such as drug resistance or bed net use could also be included, when available. Eventually, the electronic version will be placed on the Internet for general use. The aim is that the digital atlas will allow for constant updating, extracting, querying and refining of malaria risk distribution in Africa.

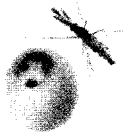
Finally it is hoped that this collaboration serves as a model for other large-scale disease information systems in Africa and in other developing countries.

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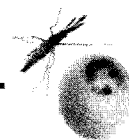
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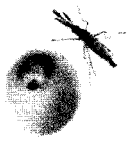


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- Snow, R. W., K. Marsh, and D. le Sueur. 1996. The need for maps of transmission intensity to guide malaria control in Africa. *Parasitology Today* 12: 455-457.
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- Omumbo, J. A., J. Ouma, B. Rapuoda, M. H. Craig, D. le Sueur and R. W. Snow. 1997. Mapping malaria transmission intensity using geographical information systems (GIS); an example from Kenya. *Annals of Tropical Medicine and Parasitology* 92: 7-21.
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- Coetzee, M., M. H. Craig, and D. le Sueur. 1999. Mapping the distribution of members of the *Anopheles gambiae* complex in Africa and adjacent islands. *Parasitology Today*. Submitted.
- Snow, R. W., E. Gouws, J. A. Omumbo, B. Rapuoda, M. H. Craig, F. C. Tanser, D. le Sueur, and J. Ouma. 1999. Models to predict the intensity of *Plasmodium falciparum* transmission: applications to the burden of disease in Kenya. *Transactions of the Royal Society of Tropical Medicine and Hygiene*. In press.
- Bagayoko, M., I. Kleinschmidt, N. Sogoba, M. H. Craig, D. le Sueur and Y. T. T. Touré. 1999. Mapping malaria risk in Mali. In preparation.
- Kleinschmidt, I., G. P. Y. Clarke, M. Bagayoko, M. H. Craig and D. le Sueur. 1999. A spatial statistical approach to malaria mapping. In preparation.



Appendix 2: Environmental Data Sets

Climate data: A topographic and climate database (CD-ROM)

M.F. Hutchinson, H.A. Nix, J.P. McMahon and K.D. Ord, 1995, Centre for Resource and Environmental Studies, The Australian National University, Canberra, ACT 0200, Australia

Topographic data: African Data Sampler (CD-ROM)

World Resources Institute (WRI), 1995, 1709 New York Ave., NW, Washington, DC 20006, USA

Population data: African population database (public domain)

U. Deichmann (uwe@ncgia.ucsb.edu), 1996, National Centre for Geographic Information and Analysis, University of California, Santa Barbara, CA 93106
<http://grid2.cr.usgs.gov/globalpop/africa>

Populated places: Geoname Digital Gazetteer v.1 (CD-ROM)

GDE Systems, Inc., 1995, P.O. Box 509009, San Diego, CA 92150-9009
<http://www.GDEsystems.com>

Elevation data: Global DEM (public domain)

EROS Data Centre (EDC), 1996, U.S. Geological Survey
<http://edcwww.cr.usgs.gov/landdaac/gtopo30/gtopo30.html>

NDVI: Artemis NOAA AVHRR NDVI Image Bank Africa 1981-1991 (CD-ROM)

Food and Agriculture Organisation (FAO) of the United Nations Remote Sensing Centre; 1991, NASA Goddard Space Flight Centre (GSFC); Africa Real Time Environmental Monitoring Information System (ARTEMIS), NASA Goddard Space Flight Centre, Greenbelt, MD 20771, USA

Global land cover classification (public domain)

R.S. DeFries, M. Hansen, J.R.G. Townshend and R. Sohlberg, 1998, Laboratory for Global Remote Sensing Studies, Department of Geography, 2181 LeFrak Hall, University of Maryland at College Park, College Park, MD 20742-8225, USA
<http://www.geog.umd.edu/landcover/8km-map.html>

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