Malaria, Deforestation and Poverty: A Call for Interdisciplinary Policy Science

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ABSTRACT

Many of the world's poorest people live in areas with high rates of malaria and the associated social and economic hardships. Many of these areas are also experiencing high rates of forest clearing and degradation. There is growing evidence that this juxtaposition of poverty, deforestation, and disease is not pure coincidence. Both health and forest policies aim to enhance human welfare, i.e. socio-economic development, but it is unclear whether these policies complement or conflict with each other because of the complex and dynamic relationship between deforestation, malaria, and poverty. We call for a cross-disciplinary research and communication program to better understand the social and environmental causes and consequences of malaria in forested areas of the developing world. Such a research strategy would systematically evaluate the relationship between deforestation and malaria incidence and burden, develop research capacity, and disseminate policy-informing research to health and environment policy makers.

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1. INTRODUCTION

Many of the world's poorest people live in areas with high rates of malaria and the associated social and economic hardships (see Figure 1). Many of these areas are also undergoing rapid and extensive forest removal and degradation (see Figure 2). While simple theories of causality cannot explain these patterns and correlations, the literature makes it abundantly clear that this juxtaposition of deprivation, deforestation, and disease is not pure coincidence. We argue that policy options for malaria control would be enhanced by a transdisciplinary approach that integrates economics, ecology and epidemiology to examine the critical nexus of malaria, deforestation, and economic development.

Figure 1. Malaria and poverty in 1995 (WHO, 2002)

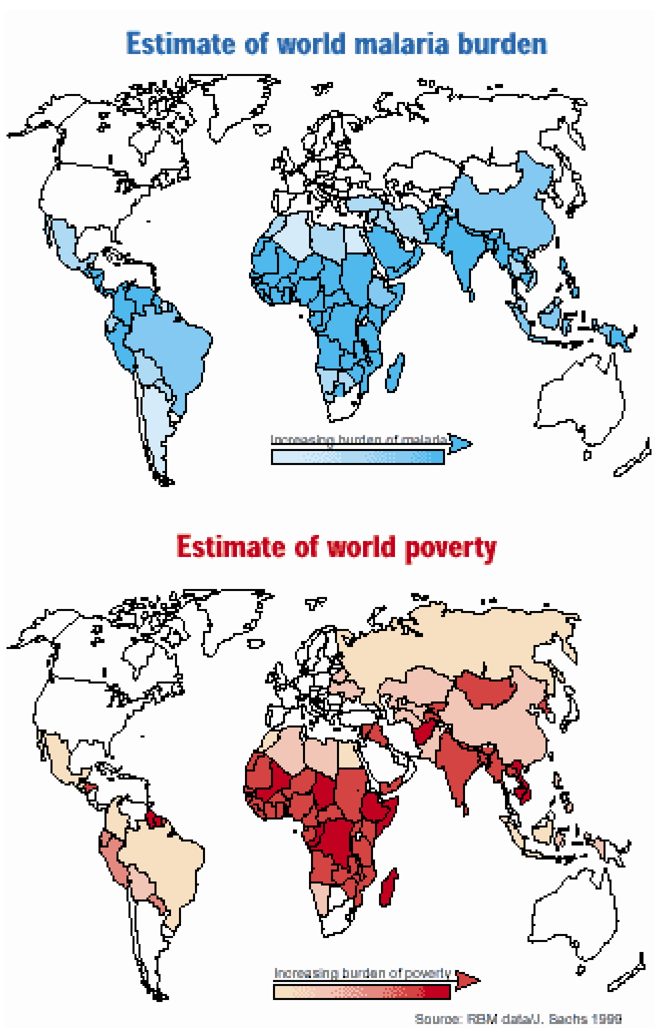
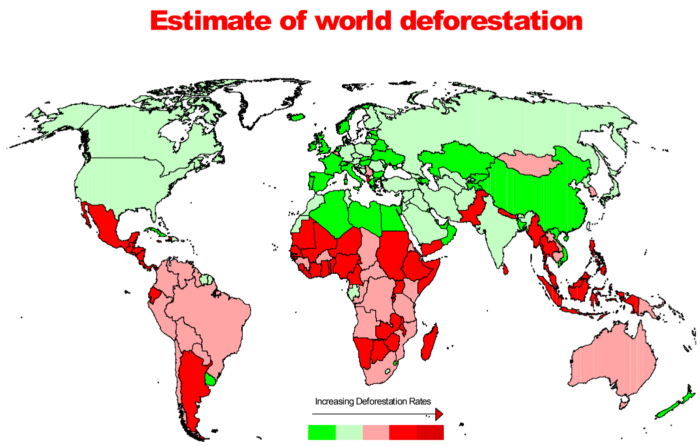


Figure 2. Forest cover change from 1990 – 2000 (FAO, 2001)



Despite billions of dollars invested in policies to reverse deforestation, eradicate malaria, and foster economic development about a third of the world's population (2 billion people) live in malaria infected areas, deforestation continues at the rate of 16 million hectares in the last decade and about half the world's populations lives on less than $2 per day. Today more people die from malaria than 40 years ago. Malaria is a 'reemerging' threat due to its expanded distribution, heightened incidence locally, and increased severity, duration and resistance to treatment. Recognizing that we live in a global society in which ecological, epidemiological and economic phenomena truly connect us all, we "cannot ignore the strategic and moral imperative of alleviating the suffering of a significant number of the world's people" (Guerin et al., 2002; p 572). Design and implementation of policies to combat malaria and its consequences requires clear understanding of the interrelations between deforestation, poverty, and malaria and the cross-effects (or unintended side effects) of policies targeting one problem on the other two problems.

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2. THE BURDEN OF MALARIA

Malaria is caused by a protozoan parasite (*plasmodium falciparum*) that completes its complex cycle of development alternating between human hosts and mosquitoes of the genus *Anopheles*. The economist Jeffrey Sachs is arguably one of the most articulate commentators on the burden of malaria:

> "The numbers are staggering: there are 300 to 500 million cases every year; and between one to three million deaths, mostly of children, attributed to this disease [malaria]. Every 40 seconds a child dies of malaria, resulting in a daily loss of more than 2000 young lives worldwide. These estimates render malaria the pre-eminent

> tropical parasitic disease and one of the top three killers among communicable diseases." (Sachs and Malaney, 2002; p 680)

Beyond mortality, malaria causes morbidity through fever, weakness, malnutrition, anemia, spleen diseases and vulnerability to other diseases. According to Bremen (2001), malarious patients experience asymptomatic parasitemia, acute febrile, chronic debilitation, and complications of pregnancy. The health consequences of malaria vary in terms of severity, but the global impact of malaria on human health, productivity, and general well-being is profound. The joint mortality and morbidity impacts of malaria are estimated to be 45 million DALYs (disability adjusted life years) in 2000 or nearly 11% of all infectious diseases (Guerin et al., 2002).

Social scientists, particularly economists, have studied the social and economic impacts of malaria at several scales, peering inside families, looking across households and communities, and comparing entire nations and continents. What they have found is remarkably consistent - malaria imposes substantive social and economic costs and impedes economic development through several channels, including but certainly not limited to, quality of life, fertility, population growth, saving and investment, worker productivity, premature mortality and medical costs (Sachs and Malaney, 2002).

Economists have attempted to put an economic value on this burden by measuring the impacts on (a) households, (b) health systems, and (c) national economies. At the household level, malaria imposes both direct and indirect costs. Direct costs include time lost from work and medical treatment costs (including transportation and medical care). Indirect costs, which are typically harder to measure, include loss of work efficiency and time and work reallocation within the household. For children in particular, indirect costs also include nutritional deficiencies, cognitive and educational disabilities, and physical retardation. Pain and suffering are clearly substantial indirect costs but are perhaps most difficult to quantify and monetize. In general, long term effects such as child development and resistance are unknown (Hutubessy et al., 2001).

Costs to health systems typically include treatment and medication costs. In most economies, households pay subsidized amounts for treatment and medication, with the rest of the cost borne by the health system. There are also opportunity costs for displaced and or delayed treatment and medication for others. Caregivers also experience lost workdays.

These direct and indirect impacts above can collectively impede economic development and growth. Malaria is estimated to cause a decline in economic growth in the range of 0.25% to 1.3% of per capita GNP growth in tropical countries, even after accounting for initial endowments, overall life expectancy and geographic location [Guerin et al., 2002; Sachs and Malaney, 2002]. To the extent that slow economic growth limits funds for malaria control, there is a vicious cycle of poverty and malaria that diminishes economic opportunities for a large number of the world's inhabitants.

3. ECOLOGY OF MALARIA: DEFORESTATION IMPACTS

The ecological basis for disease dates back at least as far as the writing of *On Airs, Waters, and Place* by Hippocrates in 400 B.C. Wilson argues persuasively that without an "ecological" perspective on the life cycles of parasitic microorganisms and the associated infectious diseases our understanding and therefore control of diseases would be inadequate (Wilson et al., 1994; Wilson, 1995). Infectious diseases are perhaps best viewed as part of a larger **human ecology** in which "human social systems, economic activities, interactions with the environment, and lifestyles represent some of the key domains of interaction that affect infection and disease risk" (Wilson, 2001). Each environmental change, whether occurring as a natural phenomenon or through human intervention, changes the ecological balance and context within which disease hosts or vectors and parasites breed, develop, and transmit diseases.

In general, vector-borne anthroponoses such as malaria are more strongly affected by environmental factors influencing the abundance and survival of the vector. Indeed, Smith et al. (1999) attribute 70-90% of the risk of malaria to environmental factors. The variety and magnitude of environmental influences on this vector-borne disease is enormous (Wilson, 2001). Not only do abiotic elements such as precipitation and temperature affect the abundance of mosquito vectors and the development of parasites within the vectors, but also biotic factors operating through deforestation, agriculture, and housing construction may influence vectorial capacity. The impact of deforestation on temperature, precipitation, and vegetation reveals the interacting and correlated nature of these environmental influences.

Consider at least six pathways through which forest management and deforestation can affect malaria infection and disease (Aron et al., 2001; Wilson, 2001; Patz et al., 2000; Walsh et al., 1993).

1. Deforestation changes the ecology of a disease vector and its options for hosts. Whereas the forest floor in primary growth tends to be heavily shaded and littered with a thick layer of organic matter that absorbs water and renders it quite acidic, cleared lands are generally more sunlit and prone to the formation of puddles with more neutral pH which can favor specific anopheline larvae development (Patz et al., 2000). These puddles or pools are more likely to form on flat terrain.

2. Deforestation can change local climate and thereby affect the spread of disease by reducing moisture held by the vegetation and raising ground temperatures. Higher temperatures can increase the rate at which mosquitoes develop into adults, the frequency of their blood feeding, the rate at which parasites are acquired, and the incubation of the parasite within mosquitoes (Walsh et al., 1993). For example, deforestation and its related activities have produced new habitats for *Anopheles darlingi* mosquitoes and have caused malaria epidemics in South America (Walsh et al., 1993). The different species complexes in SE Asia (*A. dirus, A. minimus, A* *balabacensis*) have been affected in different ways by forest clearance with different impacts on malaria incidence (Walsh et al., 1993).

3. Deforestation is often the beginning of a variety of land use changes. These changes may include agriculture and livestock, plantations, human settlement, increased use of regenerating forests, road construction, and water control systems (dams, canals, irrigation systems, reservoirs). Network of irrigation ditches, canals and impoundments, as well as puddles from road construction, can improve vector habitats. Livestock can change vectorial capacity. Rubber plantations in Malaysia encourage *A. maculatus*, whereas erythrina (with their bromeliads) encouraged *A. bellator* in Trinidad. Use of insecticide in follow-up agriculture can increase vector resistance (Wilson, 2001).

4. Deforestation is accompanied by migration that may enhance the spread of malaria. As shown in the case of gold miners in the Brazilian Amazon, migrants typically have little previous exposure and therefore lower natural immunity (Castilla and Sawyer, 1993). Moreover, migrants introduce the additional complication associated with administering health services to transient populations—inadequate medical follow up and possible side effects. Although incomplete treatment can relieve fever, the underlying malarial infection persists as the migrant moves and potentially transmits the disease to other locations, presumably on the deforestation frontier.

5. Ecosystem change such as deforestation has several putative climate impacts via the role of trees in the carbon cycle and regional weather patterns. Where the scale of deforestation is large, e.g. the Amazon basis, the effects on temperature and moisture and therefore on vector habitats can be quite significant (Wilson, 2001).

6. Ecosystem change such as deforestation can play a role in antibiotic resistance that has become a major concern for several *plasmodium* species. Resistance evolves through fundamental principles of natural selection and evolution, including diverse factors such as extent of treatment, nature and site of antibiotic action, or genomic complexity of the parasite (Wilson, 2001). Greater virulence results from genetic changes that occur by chance mutation, drift, or selection. While ecological change permeates the process, it is difficult to delineate the roles of specific forms of change such as deforestation.

4. SOCIETAL AND INDIVIDUAL RESPONSES

Societal response to malaria essentially consists of preventive (control) and curative (treatment) approaches; the efficacy of both is affected by the mediating role of ecological and behavioral factors at the individual, community, and regional levels. The main form of prevention is vector control, that is, destroying mosquito habitat and mosquitoes themselves at various stages of their life cycle by clearing vegetation, modifying river boundaries, draining swamps, applying oil to open water bodies, screening houses, and spaying insecticides (e.g. DDT). Individuals can also engage in preventive behaviors by using insecticide treated bednets and minimizing exposure by controlling activities in the early morning and evening hours. Malaria vaccines represent a potential prevention strategy that is very much in an incubation stage (Guerin et al., 2002).

Prompt and effective treatment is widely recognized as probably the most cost-effective element of malaria control (Goodman et al., 1999). Because the rate of infectious contact is a key factor in disease transmission, prompt individual treatment is an important form of population-level prevention (Wilson, 2001). Malaria from *plasmodium vivax* rarely kills, even though it causes recurring and debilitating infections, without the necessary two weeks of treatment. Unfortunately, people in endemic areas have little or no access to treatment, which when available, is commonly inadequate because of poor quality drugs.

Laboratory-based diagnosis is a critical element of any treatment program and would ideally involve some form of 'bloodwork' through microscopy, dipstick, or test strip. Unfortunately treatment is given mostly on the basis of clinical or self-diagnosis, which are often inaccurate because signs and symptoms of malaria are non-specific and overlap with other febrile infectious diseases, and because the subjective sensation of fever is unreliable. As a result, society engages in unnecessary and inappropriate treatment and drug use that (a) can be toxic (side effects), (b) incurs unnecessary costs for individuals and health systems, and (c) increases parasitic resistance (Guerin et al., 2002)

An essential ingredient of almost all prevention and cure packages is local awareness of the malaria control alternatives. For example, mortality from severe malaria (which can result in organ failure, cerebral malaria, and severe anemia) continues to be high because patients arrive in an advanced state, even though home or village-based rectal administration of artesunate is a promising approach (Guerin et al., 2002). Similarly, minimizing activities and seeking protection from mosquitoes at dawn and dusk can substantially lower exposure and infection.

As with other diseases, malaria has an unequal effect on different members of the population; pregnant women and children are most susceptible. Given that the intensity of malaria transmission and therefore the likelihood of control depends on the relative abundance of and contact patterns among susceptible, infected, infectious, and immune individuals, it is essential to target mothers and children in treatment (Guerin et al., 2002). The immediate economic burden on households from losing a mother is devastating, whereas childhood malaria imposes future burdens.

Perhaps the biggest threat to malaria control—be it prevention or treatment—is the increasing resistance to pesticides and drugs. Optimal control and treatment maximize the useful life span of insecticides and drugs. Resistance is more likely to emerge when background immunity is weak, parasite numbers in individuals are high, transmission is low, and insecticide and drug pressure is intense. P. *falciparum* has become variably resistant to all drug classes except the artemisinin derivatives. Multiple economic factors influence the inappropriate use of drugs and insecticides (Reed et al., 2002).

Remotely sensed data and geographical information systems (GIS) are becoming an important component of the policy tool kit, particularly for the development of early warning systems. Remotely sensed data are increasingly being used to monitor climatic phenomena and thereby forecast the spread of disease (Epstein, 1998). When integrated in a GIS, remote sensing can aid in the monitoring of disease carriers (vectors), breeding sites, and animal reservoirs in both marine and terrestrial ecosystems.

Utzinger et al. (2001) make a compelling argument for an integrated approach to malaria control that relies on environmental management at its core. They argue that although society is engaged in a wide variety of efforts to combat malaria, including new drugs, engineered malaria-resistant mosquitoes and vaccines, these efforts will take time and are not guaranteed to deliver. In the interim, the best option may lie in environmental management for vector control, including vegetation clearance, management of water bodies (*e.g.*, modification of river boundaries, drainage of swamps, reduction of standing water, application of oil to open water bodies), and use of screens and bed nets.

5. THE ROLE OF FOREST CONSERVATION POLICY

Till now, we have enumerated the potential benefits of reducing malaria incidence, pathways by which deforestation may influence malaria, and choices for public health interventions. There is also a substantial literature claiming that deforestation is a significant development policy issue (Deacon, 1994; Angelsen and Kaimowitz, 1999; Foster and Rosenzweig, 2003). This research on the causes and consequences of deforestation, including income and poverty, has identified many public interventions to promote forest conservation (slow deforestation). Both forest and health policies ultimately aspire to enhance human welfare. Unfortunately it is unclear which of these policies complement and which conflict with each other because of the complex and dynamic relationship between deforestation, malaria, and poverty (see Wolman, 1995 for a similar set of concerns). We consider it critical to incorporate deforestation into research on malaria, not only because of the the potential linkages enumerated earlier but also because of linkages through the human drivers and consequences of malaria and deforestation. We present five reasons why it is important to understand the role of deforestation in linking malaria to economic development.

1. Deforestation is an integral part of life and the landscape in almost all parts of the world with high malaria rates (Donohue, forthcoming; Wilson, 2001). Any evaluation of malaria control activities that ignores the role of deforestation and its associated ecological and behavioral dimensions may suffer from serious omissions and therefore produce biased findings.

2. Deforestation is not merely the exogenous (remote control) removal of forest cover (Patz et al., 2000). It is the beginning of an entire chain of activities ranging from forest clearing, farming, irrigation, livestock, non-timber forest product collection that have ecological [vector habitat] as well as behavioral [exposure and transmission] consequences for malaria.

3. Millions of rural households depend directly on a wide variety of forest products and services (Byron and Arnold, 1999). By lowering local people's natural wealth, deforestation can reduce household capacity to invest in health care and pay for malaria prevention and treatment. At the same time, deforestation may increase the wealth of other households, who will then be better able to avoid and cure malaria.

4. Conservation policies aimed at slowing deforestation will impact malaria (Ault, 1994; Taylor, 1997; and Walsh et al., 1993)**.** Sustainable forest management is an important element of local development policies, as donor agencies and local policy makers seek to take a more integrative view of people in the natural landscape. The resulting changes in land cover, as well as changes in how people interact with the forest, have implications for malaria.

5. Malaria and deforestation are central elements of the vicious cycle of poverty in rural areas of developing countries. In simplistic terms, malaria could be considered to 'cause' deforestation, because malaria can make people poorer and poverty has been found to 'cause' deforestation under some conditions. In reality, the linkages are more complex and site-specific. For example, Sawyer (1993) argues that high rates of malaria encourage forms of land use in which men work as day laborers (in logging or ranching), allowing their wives and children to live in towns with relatively lower threat of malaria, rather than establishing family farming. It is often difficult to disentangle causality in situations like these. It is clear, however, that "many of the most critical health problems in the world today cannot be solved without major improvement in environmental quality" (Smith et al, 1999; p 583).

6. CURRENT STATE OF KNOWLEDGE

Despite the emerging body of knowledge about the economic and ecological causes and consequences of malaria described in the previous sections, our understanding of these complex issues remains incomplete and inadequate (McMichael et al., 1998). In particular, no study has comprehensively related deforestation to malaria incidence and burden by analyzing a panel data set. We believe that an interdisciplinary approach integrating economics, epidemiology, and ecology could address many of the knowledge gaps distilled below:

1. **Malaria is highly contextual, with incidence and transmission depending on local conditions, perturbations, and catastrophes**. Thus, any attempts to evaluate the relationship between forest conditions and malaria should take an individual-level multi-factor approach to incorporate the diversity and heterogeneity of the ecological, epidemiological, and economic phenomena surrounding malaria. Nevertheless, modeling of heterogeneity and diversity seems to be the exception rather than the rule in research on behavioral dimensions of malaria (see small body of research referenced in Section 7.1).

2. **Policy evaluations of malaria control have typically overlooked the full range of ecological factors in the life cycles of parasites.** Similarly, eco-epidemiological assessments have not considered the full range of interactions within and between society and nature. This lack of a

human ecology perspective of malaria is reflected by the insufficient understanding and modeling of acquired immunity, exposure history and antibiotic and pesticide resistance.

3. **This incomplete human ecology of malaria, is best exemplified by the insufficient and partial modeling of behaviors—at the societal, community, household and individual level—including a wide variety of observable and unobservable activities related to exposure, prevention and treatment**. Mechanistic models of human actions do not fully account for human responses and reactions to changing ecological and economic conditions. In particular, typical cost of illness estimates based on lost productivity grossly under-represent socio-economic impacts on individuals and households.

4. **Several aspects of malaria involve long gestation periods such as acquired immunity, vectorial and parasitic resistance, child development, and cumulative well-being**. Yet, almost no existing study fully incorporates these dynamic processes or measures the long-term benefits of malaria control.

5. **Forests are one of the primary ecological factors influencing malaria incidence and transmission.** Yet, there is only a thin empirical literature on malaria in forest regions, at least in terms of research that considers any socio-economic factors including behaviors (see Section 7.1 for a partial list of papers). What is perhaps most limiting is the fact that none of the studies in this literature comprehensively consider the resource role of forests in contributing goods and services and, thereby, changing household and individual wealth.

6. **Malaria control and treatment is an example of a real world program that produces nonrandom (non-experimental) data with the associated problems of making reliable inference and conclusions**. Evaluation science has taken significant strides in terms of methods for data collection and analysis that can address the concerns of heterogeneity, diversity and dynamics (endogeneity). Unfortunately, evaluations of malaria control appears to have not fully utilized this methodological gain, with few long term field studies collecting repeated cross-sectional, cohort, and or panel data to complement classical laboratory experiments.

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7. TOWARD A COMPREHENSIVE RESEARCH PROGRAM

An integrated, comprehensive research program is needed to develop a better understanding of the critical nexus of malaria, deforestation, and economic development. We propose and describe a four pronged research program in this section. The primary task should be to identify or develop a quasi-randomized policy experiment in malaria control that takes place across a range of deforestation levels and rates, collect longitudinal data, and then apply appropriate analytical methods to evaluate the link between deforestation and malaria incidence. Given the current limited understanding of the dynamics of malaria and forest cover, we argue that this empirical task should be preceded by (a) scoping to establish a common set of issues that cut across the disciplines and generate hypothesis, and (b) developing a conceptual framework that will foster model building and suggest dependent and independent variables. Equally critically, the empirical task must be followed by capacity building and policy dissemination.

7.1 Hypothesis Generation

Given the uncertainties surrounding data and methods employed in the design and evaluation of malaria programs and policies, it is important to begin the comprehensive research program with the establishment of a common ground that reflects the collective initial understanding of the "knowns" and "unknowns" by a team of ecologists, economists and epidemiologists. This would be followed by a meta-analysis of all empirical studies on the economic and environmental determinants of malaria incidence in forest regions. As Stanley (2001: p 131) describes it, "[meta-analyses] act as intelligent agents searching through mountains of potentially contradictory research to uncover the nuggets of knowledge that lie buried underneath." Experience with meta-analyses of forest management, agroforestry adoption, and other natural resource management issues has shown that it is a structured and effective mechanism for identifying gaps in the literature (Pattanayak et al., 2003; Beach et al., forthcoming). When the phenomenon or process is similar enough across the studies, meta-analysis is also a helpful way to generate hypotheses.

Consider for example a small but growing body of studies on the behavioral basis for malaria transmission and control that have used community, household and individual data from tropical regions of South and Southeast Asia, South America and Sub-Saharan Africa. These include Bhati et al. (1996), Castilla and Sawyer (1993), Castro (2002), Castro and Singer (2001), Cho-Min-Naing, et al. (2000), Lansang et al. (1997), Perz (1997), Sharma et al. (2001), Vosti (1990), and Wang'Ombe and Mwabu (1993). The studies use a varied mix of factors in their analysis. Threfore, it is not surprising that they find a wide variety of socio-economic and environmental factors, including but not limited to wealth, knowledge and awareness of the malaria problem, age, gender, and education, associated with malaria transmission. While these studies generate interesting hypotheses about the behavioral basis of malaria, they have not definitively identified behavioral factors that <u>cause</u> malaria. They also reveal that acquired immunity (previous exposure) and bacterial resistance has been excluded in modeling local malaria incidence.

7.2 Conceptual Framework

The next step of a comprehensive approach would be to develop a cross-disciplinary analytical framework that guides the choice of dependent and explanatory variables and confounding factors, as well as functional form and dynamics. The framework should draw on three strands of literature: socio-economic evaluation of disease control policies (Singer, 1989; Gersovitz and Hammer, 2001); theoretical and applied epidemiology (Anderson and May, 1991; Nelson et al., 2000); and ecology of infectious diseases (Wilson, 2001; Wilson et al., 1994).

Singer's (1989) introduction to socio-epidemiological research for tropical disease control is a useful starting point for conceptual issues in evaluating infectious disease control. Recent work by Gersovitz and Hammer (2001) considers a more general structure of private and public investments in the context of externalities created by individual prevention and care decisions. While individuals consider only controllable (non-externality) parts of different costs attributed to the infections and treatments, society must evaluate the full (internal and external) costs of individual behavior. Gersovitz and Hammer show that the relative importance of prevention and cure strategies depends on (a) disease ecology, (b) infection outcomes, (c) relative costs of interventions, (d) targeting, and (e) individual behaviors.

This framework for evaluating costs and benefits can be enriched with insights from the epidemiology literature. First, malaria transmission depends on local conditions, local perturbations, and local catastrophes, even down to the level of the individual where differences in epidemiological form, exposure history and health status create highly specific causes. Second, because malaria is a complex multi-faceted process, understanding and combating it requires an integrated approach with a central role for environmental management (Ault, 1994; Utzinger et al., 2001).

Wilson (2001) and Aron et al. (2001) offer two additional insights from ecology. First, various ecological factors affect the risk of infectious diseases in diverse and multiple ways, calling for an approach that recognizes that multiple, indirect and non-linear effects are universal rather than exceptional. Collectively, these indicate that simple predictions are deceptively difficult and even the best predictions will be accurate only in specific contexts. Second, multifactor multivariable interactions often require some assessment of system dynamics. For example, several aspects of malaria incidence and impacts have long gestation periods such as acquired immunity, resistance to insecticides and drugs, and child development. Yet, there is little evidence on the long-term benefits of malaria control. Dynamics are also reflected in interactions across space, calling for spatial statistical investigations of disease ecology during environmental change.

7.3 Empirical Strategy

An empirical strategy must address three sets of inter-related issues: (a) empirical factors and variables, (b) data collection, and (c) analytical methods.

Identify outcomes and factors

It is first necessary to consider the full range of factors that are critical for empirically linking human health, economic development and bio-physical environment. Most obviously, this requires identifying and defining **outcomes** of sustainable development in terms of wealth and environmental conditions, in addition to health status. While a host of environmental factors are of potential interest, we have argued for a focus on extent of forest cover and forest condition. These factors are rarely considered in empirical models. The set of explanatory factors should include socio-economic, demographic, environmental, health, and public health policy and programmatic **factors**.

Data collection

Although researchers can employ an array of sophisticated analysis to remedy defects in available data, clearly 'prevention' in the form of careful data collection is significantly superior to 'cure' in the form of *ad hoc* statistical fixes (Heckman et al., 1999). Longitudinal data sets – and particularly panel data sets – are key to addressing at least three critical issues in the types of research proposed here—heterogeneity, endogeneity, and dynamics or mobility (Rosenzweig, 2003; Cebu *Study* Team, 1992). Ideally, data should be collected at several scales, ranging from individual level health and demographic data, to household level economic information, to community and regional level environmental statistics and policy factors. Geographical information systems (GIS) could be used to integrate data layers across space and time (Jacquez, 2000).

Methods of analysis

The goal of data analysis is to disentangle the effects that different mixes of health and forest policies, different target groups, and different environmental settings have on people's health and wealth. This calls for a range of parametric, non-parametric, and semi-parametric methods. Key lessons for empirical evaluations can be gleaned from Heckman, Lalond and Smith (1999) and Heckman and Vytlacil (2001). First, there are many parameters of interest in evaluating deforestation impacts on malaria and poverty partly because of the heterogeneity of impacts. Thus, analysis should use a variety of comparison groups and estimation methods, and should highlight and explain the differences that emerge from the use of multiple approaches. Second, there is no inherently dominant method of choice—it is conditional on (a) the ecology, epidemiology and economics underlying the problem, (b) the data that are collected, and (c) the primary evaluation questions posed in the previous tasks. The accuracy of evaluations depends on the ability to characterize the policy/program of interest, define the counterfactual scenario, and identify comparables or 'controls'. Given that deforestation and diseases are potentially large scale phenomena, it is important to consider ways to minimize contagion bias and/or measure 'macro effects of treatments' on the controls or non-participants (see Miguel and Kremer, forthcoming).

7.4 Capacity Building and Policy Dissemination

Given the contextual determinants of malaria, the research called for herein will be truly valuable only if the infrastructure for performing and disseminating this type of multi-disciplinary research is developed in the countries with the highest rates of malaria. A well-designed research program would provide opportunities for researchers in developing countries to build skills in meta-analysis, cross-disciplinary research, publication for scientific peers and policymakers, and proposal-writing for international funding.

Dissemination and outreach encompass a broad range of activities designed to inform, educate, and involve the public in the research and policy process. Dissemination can include simple mechanisms for transferring information through reports, conferences, seminars, press releases, and correspondence. Mapping disease, natural resource, and economic data through geographical information systems (GIS) may be an effective approach, allowing rapid visualization by planners and administrators (Indaratna et al., 1998; Epstein, 1998). Outreach can also involve more in-depth technical assistance and training that provide individualized assistance to specific stakeholders, such as researchers, national policy makers, local government officials, and non-governmental organizations.

In summary, we are calling for a cross-disciplinary, trans-national research program to advance understanding of the malaria-deforestation-poverty nexus by:

- Evaluating the significant pathways for malaria in tropical forested regions by distilling what is considered known and unknown by researchers in a range of disciplines;
- Identifying the critical research questions about the relationships between individual behaviors and welfare outcomes, deforestation, and malaria;
- Developing testable hypotheses about the root causes and consequences of malaria incidence and the efficacy of malaria control, including but not limited to deforestation and development policies;
- Building a conceptual framework and empirical plan for conducting cross-disciplinary research to test these hypotheses;
- Evaluating the portability of this framework to other locales, environmental stressors, and ecologically driven disease vectors; and
- Building capacity to better understand the significant pathways and key research questions regarding malaria in tropical forest regions.

The ultimate goal of the proposed program would be to understand the social and environmental causes and consequences of malaria in forested areas of the developing world and to communicate the research results to key policy makers in the public health, environmental management and development community. Towards this goal, the objective would be to develop a plan for systematically evaluating the impact of deforestation on malaria incidence and burden by analyzing longitudinal data that varies across the behavioral and policy landscape in time and space. A second equally important objective should be to treat this longitudinal data set as a prototype and evaluate the portability of the ecological and economic framework to evaluate deforestation impacts along the malaria risk-deforestation-poverty gradient across countries. With a better understanding of the dimensions and extent of the problem, public health officials, environmental agencies, and economic policy makers stand a better chance of developing strategies that can effectively counter the threat of malaria and that are complementary to better forest management, thereby improving the condition of millions of people worldwide.

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