Patterns of change in vector-borne diseases

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The statuses of vector-borne diseases have changed over recent years. How a few such diseases have changed and the primary causes of change (urbanization, increased conflict, changes in water-resource management, ecological and environmental change, and reduced health service resourcing) are the subjects of the present review. The key impacts which these primary causes have on selected vectors and the infections they transmit are tabulated. The success of vector-control programmes against onchocerciasis and Chagas disease is discussed, and the methods used to evaluate the epidemiological impact of such controls are described. Bednet programmes for control of malaria are recognized as a potential future means of reducing morbidity and mortality in children. In contrast to the success achieved in limiting Simulium and Triatoma populations through vertical programmes, control of tsetse, whilst successful in Uganda, has not been utilized to stem recent epidemics of sleeping sickness in resource-stressed settings in Central Africa.

Vector-borne diseases will continue to be a problem because of the adaptability of vectors, the potential problems of managing effective vector controls within decentralized health systems, and the influence of activities outside the health sector itself. Changes beyond the health sector can increase the problem posed by a vector and increase the frequency of transmission.

The World Development Report (WDR) entitled Investing in Health (Anon., 1993) provided extensive documentation, background and projections on global health issues, including the trends in morbidity and mortality over recent decades. This report underlined the high mortality and morbidity associated with communicable disease in sub-Saharan Africa. More recent projections (Murray and Lopez, 1994) indicate that, in this region, there is unlikely to be any major changes in the number of disability-adjusted life-years (DALY) lost because of communicable diseases over the coming decades. To address the basic health needs in Africa, the World Bank undertook an analysis of the most appropriate approaches to health provision, which it published under the title Essential Health for Africa (Anon., 1994). Several of the key issues contributing to African health, however, remain to be fully recognized, despite use of the WDR and Essential Health for Africa in formulating policy. These include the more rapid onset of epidemics and the changes in endemicity associated with the many changes in global disease patterns. In its annual report of 1996, Fighting Disease, Fostering Development, the World Health Organization (1996) summarized the problems of emergent diseases and highlighted the key causes: antimicrobial resistance (Klugman, 1990; Shears, 1993; Gold and Moellering, 1996); population growth and rural–urban migration, resulting in increased urbanization (Table 1; Mott et al., 1990; Ashton, 1992); increased conflict, with resultant mass migration creating refugees, displaced persons, and movement of non-immune populations into areas with relatively high risks of transmission; development projects involving changes in water-resource management (Hunter et al., 1993; Birley, 1995); and habitat destruction and the changing relationships between populations and the forest interface (Sharma and Kondrachine, 1991; Walsh et al., 1993). (Studies and reviews of all of these activities provide a vital resource for health-policy makers which, if appropriately used, will enable planning and prediction.

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of change.) National governments and other health providers are not only faced with resource constraints but are dependent on involvement and co-operation with other sectors. However, the rate of development change and the capacity of insect vectors to establish and adapt to new environments (Birley, 1995) in parallel with ecological change can undermine effective information and control systems and provide (already under-resourced) government health services with situations which are difficult to manage and control (Ekwanzala et al., 1996).

This review summarizes recent changes in the patterns of vector-borne disease (including schistosomiasis and dracunculiasis), emphasizing that such infections can rapidly assume epidemic proportions, are sensitive to sudden changes in control or eradication programmes, rapidly change status of endemicity, and provide public-health authorities with unplanned and unpredicted emergencies. Progress in control of onchocerciasis, Chagas disease and schistosomiasis has contributed to considerable economic and humanitarian achievements (Kim and Benton, 1995; Schmunis et al., 1996). The eradication of guinea worm now appears feasible and new strategies for control of malaria and lymphatic filariasis have been enunciated (WHO, 1992, 1993a, b, 1994), the latter disease being another candidate for global elimination. The next decade will pose problems for those planning control of parasitic and vector-borne diseases; priorities need to be set and strategies integrated into national health policy and practice as decentralization to the district level is implemented. Such problems are exacerbated by the changing statuses of the diseases and because, although the tools for diagnosis, vector control, treatment and surveillance are available for many diseases, their implementation is, with noticeable exceptions, restricted (being dependant on external donor support) or, as a result of conflict and civil disruption, not managed or ignored. The need for alternative policies is required in certain situations, when even minimal interventions may be preferable to none. It is anticipated that more reliance will be placed on remote sensing, geographical information systems, and rapid-assessment targeting, to predict epidemics on the one hand and plan and target cost-effective responses on the other (Hay et al., 1996; Thomson et al., 1996).

ONCHOCERCIASIS AND AMERICAN TRYPANOSOMIASIS

There are at least two major, ‘vertical’, vector-control programmes currently under way, both of which are based on pesticide application: the Onchocerciasis Control Programme (OCP) in West Africa (Samba, 1994; Molyneux, 1995), controlling Simulium damnosum, and the Southern Cone Initiative (SCI) for the control of Chagas disease in Latin America, controlling Triatoma infestans. Both programmes demonstrate the benefits of long-term commitment to a defined strategy, and the need for systems for epidemiological and entomological evaluation.

In the case of the OCP, the ability to change the approaches to the control, on the basis of new information from research, was a key to success [e.g. the programme area was expanded to cope with migrating vectors, new insecticides were developed to combat insecticide resistance and the microfilaricidal ivermectin was introduced (Molyneux, 1995)]. Vector control in the OCP is by weekly aerial larviciding of Simulium breeding sites in the programme area, with appropriate environmental safeguards; the programme uses seven different insecticides, representative of four different classes of chemical compounds, according to cost-effectiveness, toxicity, carrying capacity and level of river discharge (Hougard et al., 1993).

Control of triatomine bugs is by application of residual insecticide (deltamethrin) (previously benzene hexachloride, lindane) to walls of houses. Both the OCP and SCI programmes depend on detailed epidemiological indicators of performance to ensure adherence to expected public-health outputs. The OCP has also undertaken detailed studies of the economic rates of return (ERR) of onchocerciasis control (Kim and Benton, 1995), demonstrating that the investment in the pro-
<table>
<thead>
<tr>
<th>Determinants of change</th>
<th>Factors influencing change in vector-borne diseases</th>
<th>Specific examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural–urban migration (following conflict or drought, or for employment), with consequent higher rate of urban growth</td>
<td>Immune status of population and status of urban vector population</td>
<td>Increased severity of schistosomiasis and malaria; increased transmission of Chagas disease; and increased incidence of cutaneous leishmaniasis due to <em>Leishmania tropica</em> and <em>Le. major</em> in Kabul and Khartoum, respectively</td>
</tr>
<tr>
<td>High population density, development of peri-urban areas with rural interfaces, and urban construction in forest</td>
<td>Zoonotic potential increased because of changes in the behaviour and abundance of animal reservoir hosts in relation to urban and peri-urban vectors; establishment of urban zoonotic foci</td>
<td>Increases in: visceral leishmaniasis due to <em>Le. chagasi</em> transmitted by <em>Lu. longipalpis</em>; <em>Culex</em>-transmitted lymphatic filariasis; <em>Le. guyanensis</em> transmitted by <em>Lutzomyia umbratilis</em> Chagas disease</td>
</tr>
<tr>
<td>Inadequate or poor housing, sanitation and water supply and increases in small industries and construction</td>
<td>Proximity to and adaptability of forest vector/reservoirs; new breeding sites for urban vectors</td>
<td>Increases in: <em>Le. major</em> leishmaniasis in peri-urban areas (Kuwait; Amman, Jordan); <em>Schistosoma japonicum</em> in peri-urban irrigation systems (South–east Asia); <em>Aedes aegypti</em> breeding sites; spread of <em>Ae. albopictus</em> (with increased dengue risk)</td>
</tr>
<tr>
<td>Urban food projects—rice cultivation, vegetable gardens etc</td>
<td>Provision of new breeding sites for vectors</td>
<td>Increased <em>An. gambiae</em> populations as a result of urban rice culture</td>
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</tbody>
</table>
gramme to date has provided development benefits, compatible with World Bank investments in other sectors, such as transport, energy and education, of around 20%. Indicators of epidemiological and entomological impact of the two programmes have been constantly scrutinized to evaluate the success of the control. The primary indicators of epidemiological and entomological impact in the OCP were listed by Boatin et al. (1997) and can be broken down further into several categories: changes in annual transmission potential; community microfilarial load; skin-snip positivities; incidence in children, aged <5 years, born since the programme commenced; and changes in prevalence of ocular lesions. These indicators, when measured consistently over time, give a clear indication of trends and enable the detection of recrudescence. New approaches to detect recrudescence, based on molecular biology or a patch test using diethylcarbamazine, are being developed. The primary indicators for Chagas disease are the absence of triatomine bugs in post-control monitoring of houses and a decline in the percentage of serological reactivity in younger age groups since controls began. The Figure shows the changes in these SCI indicators in four countries over the period of control, from the early 1980s to 1994. The OCP and SCI parallel each other in evaluating both entomological and epidemiological parameters and using, as an important and most sensitive group, those individuals born at or after the commencement of control. In the SCI, house infestation is measured by surveillance using simple bug traps to determine the success of control and the level of re-infestation. Improvements in the construction of housing, to reduce suitable habitats for the bugs (crevices in mud walls and plant roofing material), and reductions in unplanned urban housing will contribute to the control of Chagas disease and reduce the likelihood of re-establishment of domiciliary T. infestans infestation.

AFRICAN TRYPANOSOMIASIS

In contrast to the success of vector control in Chagas disease, the use of highly effective tsetse trapping using insecticide-(delta-methrin)-impregnated traps and targets has only been applied in limited situations for sleeping sickness (SS) control, despite the evidence, particularly from Uganda, Congo and Côte d’Ivoire, that such approaches can reduce transmission and vector populations (Lancien, 1991; Green, 1994). Although traps and targets for tsetse are relatively cheap, can be made locally and do not necessarily require insecticide, deployment has generally been dependent on external donor support for SS control. Despite its devastating effect and the fact that appropriate tools for its control and diagnosis are available, SS is as serious a problem as ever in certain areas of Central Africa, particularly in Angola, the Democratic Republic of Congo (DRC), southern Sudan/Uganda and the Central African Republic (Ekwanzala et al., 1996; Molyneux, 1996).

The absence of a safe, cheap and available alternative drug means that treatment of late-stage disease is dependent on melarsoprol, an arsenical compound associated with toxic adverse reactions which result in a treatment fatality rate of around 5% (Pépin et al., 1994, 1995). Although difluoromethylornithine (Ornidyl) was initially hailed as an (albeit expensive) ‘magic bullet’, it is too costly to be utilized in any existing health system, even if logistic and supply problems could be overcome. At present, there are few if any solutions to the disastrous SS situation in Central Africa, particularly in the DRC (Ekwanzala et al., 1996): only emergency supplies of melarsoprol can have any impact on patients; skills for treatment are no longer available; diagnostic skills are inadequate or not available; and patients will never have access to any health services. Even if drug supplies become available, to reduce transmission in the absence of vector control and so act as a brake on disease development, a disease which is inevitably fatal will eliminate significant populations within endemic areas of Africa. The disastrous epidemics of the 1930s and 1960s are now being repeated in the DRC, when the surveillance and treatment system could maintain the level of endemicity at a manageable level. Figures reported by
Fig. Reduction in transmission of Chagas disease as a result of the Southern Cone Initiative. The reduction is shown, for Argentina (●), Brazil (+), Chile (□) and Uruguay (■), as a decrease in house infestation by triatomines (a) and as a reduction in the prevalence of Trypanosoma cruzi infection in man (b). The rates shown for human infection are for those aged 18 years (Argentina), 7–14 years (Brazil), <15 years (Chile) or <12 years (Uruguay). Reproduced from the report by WHO (1997), with permission.

Ekwanzala et al. (1996) clearly demonstrate that an uncontrollable major epidemic is in progress, with an impact on certain communities as dramatic as that of HIV infection.

MALARIA

Whilst the evidence from large-scale field trials in Africa of the use of insecticide-impregnated bednets for malaria control has indicated the value of the nets in controlling malaria-attributable morbidity and mortality (Nevill et al., 1996) and that their use can be as cost-effective as childhood vaccination in reducing childhood mortality, no large-scale operational programmes have been implemented. The current challenge, if this approach is to be successful, is the evaluation and testing of operational issues (which vary from situation to situation). These issues include methods of promotion, distribution and financing, the role of the private sector, the efficacy of different insecticide–fabric combinations, and sustainability by communities.

Whilst there is a particular need to reduce malarial morbidity and mortality in Africa, the potential impact of sustained use of bednets...
on malaria has been best demonstrated in China. There, the importance of the traditional use of bednets, the regular and appropriate impregnation of the nets, coverage of the population, and of good organization has been proven. The Chinese programmes have been directed against Anopheles anthropophagus and An. sinensis in four provinces where Plasmodium vivax malaria and Brugian filariasis are endemic (WHO, 1994). A trial against An. dirus in Hainan province demonstrated the progressive decline in parasite rates and the disappearance of Pl. falciparum (Curtis et al., 1991). In areas where both malaria and lymphatic filariasis are endemic, there is likely to be an impact on both infections through the use of nets. In areas where both of these diseases are hyperendemic, a dual control strategy could be more widely exploited.

**HUMAN CONFLICT**

There has been wide recognition of a dramatic increase in conflict and civil unrest over the past decade; this has increased the number of refugees to over 20 million and there are at least as many internally displaced individuals. Over 80% of refugees and internally displaced persons live in environments where: (1) vector-borne infections are endemic; (2) any change in population status, local ecology and habitats can provoke a rapid change in insect populations; and (3) health services are disrupted and any health input is usually provided by external emergency resources. Thomson (1995) summarized the approaches to the control of vector-borne disease control in emergency environments and characterized the particular threats to refugees and the internally displaced. Nájera (1996) similarly reviews the approaches to malaria control in such populations. The main threats are: lack of immunity; movement of migrating/fleeing population through infested transit areas; settlement on inappropriate land; loss of livestock (which may result in changes in vector behaviour, with increased feeding on humans); crowded conditions (promoting an increase in louse populations); stress- or malnutrition-induced immunosuppression; instability, resulting in the disruption of all government sectors, including health; reduced support from non-governmental organizations (NGO); and the inability of the private sector to provide any support. The situation in an adjacent ‘recipient’ environment may be affected by the pressure of refugees on already depleted health resources. Table 2 summarizes the impact of conflict/civil unrest on vector-borne infections.

Whilst the commonest vector-borne disease of unstable tropical environments is malaria (Nájera, 1996), typhus (caused by Rickettsia prowazekii) and relapsing fever (caused by Borrelia recurrentis) are also common, both being transmitted by Pediculus humanus humanus, the body louse. Typhus outbreaks are associated with crowded conditions, particularly in temperate climates or cooler parts of the tropics. Control by mass delousing is required if high mortality from typhus and relapsing fever is to be avoided.

**CLIMATE**

Over recent years, several studies and projections have been made to analyse the impact of global climatic change on vector-borne diseases. The uses of remote-sensing data and geographical information systems (GIS) are being developed concurrently and tested to predict epidemics of vector-borne diseases. Recent studies have suggested a relationship between the climatic fluctuations of the El Niño Southern Oscillation (ENSO) and epidemic malaria periodicity (Bouma and van der Kaay, 1994; Bouma et al., 1994a, b). Close correlation has been found between the sea-surface temperature anomalies in the eastern Equatorial Pacific and malaria epidemics in the Punjab, epidemics being more prevalent in a year with a wet monsoon following a dry El Niño year. In Sri Lanka, the reverse appears to occur, epidemics being related to drought, when river pooling provides a better habitat for breeding by the local vector (An. culicifacies). Remotely sensed data from Meteosat and the National Ocean and Atmospheric Admin-
TABLE 2
Changes in vector-borne diseases and their control as the result of conflict or civil unrest

<table>
<thead>
<tr>
<th>Disease</th>
<th>Change</th>
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<tbody>
<tr>
<td>Trypanosoma brucei gambiense</td>
<td>DISRUPTION OF COTTON AND COFFEE PRODUCTION IN BUSOGA DURING THE AMIN REGIME RESULTED IN SPREAD OF LANTANA, PROVIDING BREEDING SITES FOR GLOSSINA FUSAPES AND INITIATING TRANSMISSION OF ACUTE SLEEPING SICKNESS IN PERI-DOMESTIC ENVIRONMENTS, WITH CATTLE ACTING AS RESERVOIR HOSTS</td>
</tr>
<tr>
<td>Trypanosoma b. rhodesiense</td>
<td>EPIDEMICS OF LEISHMANIA DONOVANI IN SOUTHERN SUDAN; A CHANGED ECLOGICAL SITUATION, ASSOCIATED WITH AN INCREASE IN PH. ORIENTALIS POPULATIONS IN MATURING ACACIA/BALANITES WOODLAND, INITIALLY PROVOKED THE EPIDEMICS, WHICH WERE THEN LEFT LARGELY UNCONTROLLED BECAUSE OF CIVIL WAR, MIGRATION OF INFECTED POPULATIONS, AND SCARCITY OF TREATMENT CENTRES AND AVAILABILITY OF DRUGS (ASHFORD AND THOMSON, 1991; SEAMAN ET AL., 1992)</td>
</tr>
<tr>
<td>VISCERAL LEISHMANIASIS</td>
<td>RESURGENCE IN L. TROPICA IN AFGHANISTAN (KABUL) FOLLOWING AN INCREASE IN URBAN POPULATION DENSITY OF NON-IMMUNES BECAUSE OF CONFLICT (ASHFORD ET AL., 1992)</td>
</tr>
<tr>
<td>Leishmania tropica</td>
<td>MOVEMENT OF POPULATIONS TO KHARTOUM, BECAUSE OF CONFLICT AND DROUGHT, AND ESTABLISHMENT OF TRANSMISSION AMONGST A PERI-URBAN RESERVOIR OF NON-IMMUNES LIVING IN SHANTIES</td>
</tr>
<tr>
<td>Leishmania major</td>
<td>REFUGEE POPULATIONS SETTLED AT LOWER ALTITUDE, IN SITES WITH RELATIVELY HIGH RAINFALL; REFUGEES WITH INADEQUATE IMMUNITY OR EXPOSED TO DIFFERENT STRAINS OF Plasmodium falciparum, ABSENCE OF DRUGS AND NO CONTROL OF Anopheles gambiae</td>
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<td>MALARIA</td>
<td>MALARIA EPIDEMICS IN CAMPS (CONTROLLED BY SPRAYING TENTS TO CONTROL An. stephensi AND An. culicifacies), EXACERBATED BY INCREASE IN PREVALENCE OF Plasmodium falciparum</td>
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<td>Refugee camps in Africa</td>
<td>MASS DEPORTATION OF URBAN NON-IMMUNES TO FORCED LABOUR IN RICE FIELDS AND FORESTS; CONSCRIPTION FOR CONSTRUCTION OF DEFENCES IN BORDER AREAS WHERE MULTI-DRUG-RESISTANT MALARIA COMMONLY OCCURS</td>
</tr>
<tr>
<td>Refugee camps in Afghanistan and Pakistan</td>
<td>WEEKLY AERIAL LARVICIDING AGAINST Simulium SUSPENDED FOR 2–4 YEARS BECAUSE OF SECURITY PROBLEMS AND LOCAL CONFLICT. LEVELS OF TRANSMISSION CONSEQUENTLY INCREASED</td>
</tr>
<tr>
<td>Cambodia</td>
<td>SUSPENSION OR REDUCTION OF IVERMECTIN DISTRIBUTION BECAUSE OF CONFLICT</td>
</tr>
<tr>
<td>ONCHOCERCIASIS</td>
<td>PLANNING OF PROGRAMME FOR COMMUNITY-DIRECTED DISTRIBUTION OF IVERMECTIN WAS RETARDED BY COLLAPSE OF NATIONAL STRUCTURES; REMAINING (PASSIVE) DISTRIBUTION BY NON-GOVERNMENTAL DONORS</td>
</tr>
<tr>
<td>Sierra Leone</td>
<td>INCREASE IN REPORTED CASES 1 YEAR AFTER LOCAL CONFLICT FAILED TO CONTAIN CASES FROM PREVIOUS YEAR</td>
</tr>
<tr>
<td>Sudan and Sierra Leone</td>
<td>CIVIL WAR PREVENTS ADEQUATE CASE-FINDING, CASE-CONTAINMENT, WATER-SUPPLY CONTROL AND FILTER DISTRIBUTION</td>
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<tr>
<td>DRC, Central African Republic, Liberia and Angola</td>
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<tr>
<td>DRACUNCULIASIS</td>
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<tr>
<td>Ghana</td>
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<td>Sudan</td>
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DRC, Democratic Republic of the Congo (ex-Zaire).
istration (NOAA) satellites may be used to provide information to local facilities. The data may be processed to produce proxy ecological variables which monitor change in the distribution and condition of vegetation and the extent of rainfall (Thomson et al., 1996). Preliminary results indicate that satellite data can indicate how such variables affect certain indices of malaria transmission. The forecasting of phases of the ENSO might be used for early warning of malaria epidemics up to 1 year in advance; more up-to-date local data can be targeted via remotely sensed images and correlated using GIS. Hay et al. (1996) applied such information to mapping changes in Glossina distribution in West Africa whilst Lindsay and Birley (1996) have developed a model to demonstrate the impact of small increases in temperature on transmission of Pl. vivax malaria by An. maculipennis. This analysis shows that, at low temperatures, small increases lead to large reductions in the time for malaria development and hence a disproportionate increase in transmission (Martens et al., 1995; Martin and Lefebvre, 1995). Lindsay and Birley (1996) consider different aspects of the impact of global environmental change and emphasise that the direct effects of temperature increase on malaria will be most obvious in areas of ‘fringe’ disease, such as the highlands of Ethiopia, Madagascar and Kenya, where there have, in fact, been recent reports of epidemics. In Rwanda, increases in temperature and rainfall were associated with an increase in clinical episodes of malaria, the increase being greatest at higher altitudes.

In coastal areas, higher rainfall, increased erosion, coastal flooding, or a rise in seawater levels may affect mosquitoes which breed in brackish water, precipitating a range of effects which could follow global warming. Increased breeding of An. sundiacus in South-east Asia or a reduction in populations of the more efficient An. gambiae, through replacement by the less efficient, brackish-water-breeding, An. merus and An. melas, are two different, contrasting scenarios. Desertification has been responsible for changes in distributions of several vector species in the last two decades. Parallel changes to the distribution of An. gambiae and S. damnosum s.l. have been observed in West Africa following desertification and deforestation (Coluzzi et al., 1985; Coluzzi, 1992; Walsh et al., 1993). The ‘Savanna’ vectors, better adapted to drier environments, are increasingly found further south. Similarly, the distribution patterns of Glossina species have changed over a 15–20-year period, as habitats have been destroyed (Rogers and Williams, 1993). The close interrelation between desertification, drought and deforestation and the varying response and adaptation by vectors make predictions of the epidemiological outcomes of change difficult. However, over the next decade, as much more information becomes available, new technologies are deployed and the analyses are refined, the predictions should become more accurate. The challenge will then be to initiate relevant policies which will impact on disease-control strategies and their implementation.

DEFORESTATION

The impact of deforestation on vector-borne infections (see Table 3) has been extensively reviewed by Walsh et al. (1993). Deforestation, the result of exploitation of mature woodland of different types, from rainforest to savanna, occurs in both temperate and tropical regions. There is a well recognized impact on CO₂ levels and erosion, with losses of biodiversity, nutrients and indigenous cultures. The reasons for the process are various and include collection of fuel wood for domestic use and urban demand, commercial hardwood exploitation (logging), agricultural development for livestock raising, mining, hydro-power, and road construction. Many of these processes are common throughout Africa, Asia and South America. All major vector-insect groups are affected by deforestation. In South America, there is a considerable impact of deforestation on the epidemiology of Chagas disease (Schofield, 1982), the leishmaniases, and malaria, with epidemics resulting. Jungle mining operations in South America and Asia are linked to increased malaria risk. The problems of the forest-fringe–malaria interface,
TABLE 3
The ways in which deforestation has affected or may affect vector-borne diseases

<table>
<thead>
<tr>
<th>Disease</th>
<th>Change</th>
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<tbody>
<tr>
<td>Malaria</td>
<td>Increase in southerly distribution of <em>Anopheles arabiensis</em> in West Africa (Coluzzi, 1992); <em>Anopheles darlingi</em> expansion in Amazonia through expansion of breeding sites due to road construction, in eroded land after clear-felling and around mine workings. In South–east Asia, deforestation has reduced <em>An. dirus</em> populations and permitted expansion of <em>An. minimus</em>, changes in plantation practices and reforestation could promote return of <em>An. dirus</em> (Sharma and Kondrachine, 1991)</td>
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<tr>
<td>Leishmaniasis</td>
<td><em>Leishmania mexicana</em>/<em>Lutzomyia olmeca</em> and <em>Le. guyanensis</em>/<em>Lu. umbrotalis</em> cycles resulting from human penetration into the forests. <em>Lutzomyia guyanensis</em> is a threat to populations at forest edge. Walsh <em>et al.</em> (1993) discuss specific topics relevant to settlements in forests. A <em>Leishmania amazonensis</em>/<em>Lu. flaviscutellata</em> cycle is a risk in South American forests but the fly is mainly zoophilic. A <em>Le. brasiliensis</em>/<em>Lu. wellcomei</em>/<em>Lu. whitmani</em> cycle is a major risk in rain forest following penetration by road building or mining, and in peri-urban settlements.</td>
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<tr>
<td>Onchocerciasis</td>
<td>Reduced transmission of <em>Onchocerca volvulus</em> by <em>Simulium neavei</em> in East Africa because of deforestation. Southerly movement of <em>Si. sirbanum</em>/<em>Si. damnosum</em> in West Africa through deforestation, with increased risk of blinding onchocerciasis.</td>
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<tr>
<td>Schistosomiasis</td>
<td>Deforestation favours expansion of <em>Schistosoma haematobium</em> as heavy forest does not provide good habitat for <em>Bulinus</em> or <em>Biomphalaria</em> snails. <em>Schistosoma intercalatum</em>, a forest-associated species infecting man, will decline as forest is destroyed.</td>
</tr>
<tr>
<td>Loaiasis</td>
<td>Forest destruction reduces habitat of <em>Chrysops</em> vectors, with consequent reduction in incidence of disease.</td>
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which is complex and variable, are reviewed extensively by Sharma and Kondrachine (1991), who describe examples from South–east Asia.

WATER RESOURCES

There have been extensive studies on the impact of major water-impoundment schemes such as the Aswan High Dam, the Volta Lake Dam in Ghana, and the Senegal River Basin Dam; the effects of each of these schemes were summarized by Hunter *et al.* (1993). An extensive study on forecasting the implications of water-resource development by Birley (1991) provides a comprehensive list of guidelines for assessing the impact of any change in water-resource management. This approach is complemented by Birley (1995) in a monograph entitled *Health Impact Assessment of Development Projects*, which, although not restricted to vector-borne diseases, emphasizes the likely changes in disease patterns which development change will induce.

The most recent, major problem associated with dam construction has been the intensive outbreak and increased prevalence of schistosomiasis in the Senegal River Basin in West Africa following the construction of the Diama Dam at St Louis to prevent the inflow of salt water and so provide a freshwater reservoir for irrigation purposes. Recent epidemiological investigations of the area upstream of the dam, between Richard Toll and the Manantali Dam, in Mali, give serious concern in respect of the dramatic increase in prevalence of both urinary and intestinal schistosomiasis in areas where malaria was previously the most important problem (Piquet *et al.*, 1996). The impact of the dam on local health has been shown to have been seriously underestimated.

Whilst the major attention of health and development planners has been focused on
large-scale projects, smaller impoundments are likely to have a much larger overall impact (Jewsbury and Imevbore, 1988). ‘Microdams’ have several functions, are more transitory, and develop at a rapid rate; their control and the control of the population who use them are less subject to management than larger schemes. In general, around such dams, there is a high degree of human–water contact, a closer association with settlements and limited, organized health facilities. The major vector-borne infections associated with such impoundments are dracunculiasis, schistosomiasis and malaria. In areas of endemic lymphatic filariasis, there may be an increased severity of clinical disease because of increases in the intensity of transmission (Hunter, 1992). Inappropriate spillway design may also provide breeding sites for *Simulium*, thereby increasing the risk of *Onchocerca volvulus* transmission.

Many irrigation schemes associated with water-resource management involve the creation of agricultural monocultures, particularly of rice and sugar-cane. Several intensive studies of the associations between rice cultivation and vector-borne diseases have been published (see Service, 1984, 1989a, b). Although malaria and schistosomiasis have been particularly associated with rice cultivation, the associations are not predictable. In malaria, the efficiency of the local *Anopheles* species as a vector, the impact of the rice cultivation on the succession of mosquito species, and the impact of pesticides and fertilizer on the mosquito population are important variables (Service, 1989a; Coosemans and Mouchet, 1990; Birley, 1995). Lindsay et al. (1991) reported that, despite the perennial transmission of malaria in The Gambia in an irrigated–rice scheme, there was less malaria in villages within the scheme than in control villages because of the improved living standards that the scheme brought; villagers in the scheme were able to buy bednets and had improved access to antimalarials.

Throughout the tropical world, increased rice cultivation usually leads to an increased risk of schistosomiasis (Blas, 1989) and rice cultivation in South–east Asia is also associated with an increased risk of Japanese B encephalitis (JBE) transmitted by *Culex tritaeniorhynchus*; there is a particularly enhanced risk if there are adjacent pig populations, which act as reservoir hosts of JBE (Birley, 1995).

**DISCUSSION**

This review has sought to draw together the key factors which have, in recent years, changed the pattern of vector-borne diseases. It is clear that, given the biological characteristics of insect vectors and their inherent capacity to adapt rapidly to environmental change, it can be expected that epidemiological patterns will also continue to change.

There has been considerable progress in several control programmes in the past 20 years. It can be expected that progress will be maintained in the control of Chagas disease but bednets for malaria control and tsetse traps still require to be introduced into sustainable programmes, guided by operational research.

The dominant forces which will determine the rate of change in the epidemiology of vector-borne disease will be the processes of urbanization, habitat, environmental, ecological and climatic changes, conflict and civil unrest. However, additional forces will contribute, particularly: the resources of the health systems; the ability of reformed health systems to undertake disease surveillance and control at district level; the level of donor support to any vertical control programmes; the ability of other sectors to become involved in improving health status by appropriate policies (e.g. agriculture, forestry, water resources); the capacity to utilize, in a sustainable way, the community as agents of surveillance and management; the need to maintain appropriate applied research; the commitment to appropriate human-resource development; and the ability of health-policy makers to communicate and disseminate available knowledge. Whilst many of these prerequisites for improved health would be widely accepted, their implementation is less likely to be achieved.
It is clear that our knowledge of, and capacity to predict the rapidly changing epidemiology of vector-borne diseases can assist those involved in control, should such information be applied. However, unpredictable events will continue to occur in such highly complex and variable systems.

REFERENCES


