Introduction

IN THE ASIA PACIFIC REGION, MALARIA ELIMINATION SUCCESS STORIES ABOUND. Taiwan successfully eliminated malaria in 1965, aided by commitment from the government, community, and international organizations.(1, 2) Australia successfully ended its malaria transmission in 1981.(3) A year later, Singapore was certified malaria-free; the Maldives and Brunei followed suit in 1984 and 1987, respectively.(4–6) These successes have been attributed to a combination of vector-control techniques including indoor residual spraying of insecticide, environmental management, and widespread surveillance measures. Additional progress was made in Vanuatu, a South Pacific country located near the Buxton line that defines the easterly limit of the Anopheles in the Pacific. Through a combination of mass antimalarial drug administration, insecticide-treated bed-net distribution, and a high degree of community involvement, malaria was eliminated from the island of Aneityum in 1991.(7) Some countries nearly achieved elimination during the World Health Organization's Global Malaria Eradication Program (1955–1969). Such countries faced the risk of malaria resurgence following relaxation of control measures when cases lessened. Sri Lanka suffered a major resurgence of malaria following near elimination in 1968, resulting in high death rates after relaxing control efforts when the numbers of cases were low.(8–10) Dramatic progress has been made since then through constant control efforts, and malaria elimination is back on the agenda again for Sri Lanka and many other countries in the Asia Pacific.(11)

Today countries in the region continue to make significant strides toward elimination, progressively shrinking the regional malaria map from China and the Korean Peninsula in the north, and from Vanuatu and the Solomon Islands in the south. Between 2000 and 2009, a reduction of more than 50% of cases was achieved in Bhutan, China, the Democratic People's Republic of Korea, Republic of Korea, the Solomon Islands, Sri Lanka, and Thailand, and reductions of between 25% and 50% have been recorded in Malaysia, Philippines, and Vanuatu.(3)

The eleven countries in the Asia Pacific Malaria Elimination Network (APMEN) have each declared the short- or medium-term goal of eliminating malaria at a national or subnational level.(12) APMEN countries represent a wide range in terms of size, economy, geography, and physical characteristics. There are nations comprised of islands, such as Vanuatu, with 240,000 people living on more than 80 islands, and Indonesia, with a population of 232 million on more than 17,500 islands, and mainland giant China, with 1.3 billion people across 9.6 million km^2. Countries[1] range from low- to high-income, with the annual gross national income (GNI) per capita ranging from US$1,920 to $19,890. Health expenditure likewise spans a broad range across the 11 countries, from $55 to $1,108 per capita annually.(13) Geographically the countries represent the extremes in altitude from the Himalayas to tropical lowland islands.

In addition to geographical and economic variations, differences in epidemiological and biological conditions present particular challenges for malaria control and elimination in the region. One significant challenge for APMEN countries is the migration of populations across national borders and between malaria-endemic and non-endemic areas. Human migration, especially among vulnerable populations such as undocumented or seasonal workers, varies enormously by economic and geographic circumstance, and greatly increases the risk of malaria importation and outbreaks. Bhutan has a significant amount of migrants entering into the country through the southern border with India for long and short-term work projects. An example of this trend is found in the district of Sarpang, which borders India and accounts for the majority of cases in the country. In 2006, 40% of confirmed cases in this district were considered imported.(14, 15) Similarly, a great deal of Thailand's malaria lies along its border with Myanmar, highlighting the specific problem of border areas.(16)

A national malaria program's ability to address imported malaria relies on functional cross-border collaboration and a strong surveillance system.(17) APMEN countries are at the forefront of this work. Thailand has set up programs for free access to diagnosis and treatment for people living near the Myanmar border area, regardless of their nationality.(18) Similarly, China is working along its border with Myanmar to boost the diagnosis, treatment, and prevention of malaria due to the high proportion of cases being imported; in 2009, 63% of all cases in this region of China were imported.(19) In several APMEN countries, surveillance activities are integrating the newest technologies. One example is a web-based case-reporting system in China that uses mobile technologies to enable remote health staff to report cases of malaria directly into the malaria control program database. The Solomon Islands and Vanuatu use geographical information systems for mapping malaria cases and coverage of interventions, enabling workers there to effectively track progress in their efforts to achieve elimination.

1 Figures for gross national income (GNI) and health expenditure do not include the Democratic People's Republic of Korea, for which no data were available in the World Bank's World Development Indicator database.

Another challenge facing the region are the different vector characteristics of mosquitoes in the Asia Pacific.(20) Many of the malaria-transmitting mosquitoes in this region are outdoor biting and outdoor resting, making traditional vector control measures such as insecticide-treated bed nets and indoor residual spraying of insecticide much less effective.(20, 21) Aggravating the situation is dense forest malaria, which is contracted mainly in mountainous areas where few people live. Transmission occurs among workers, such as those found on China's Hainan Island, who are unprotected by malaria prevention measures because they sleep in temporary shelters.(18) To interrupt transmission in these areas, it is critical to reach these populations with effective interventions.(22)

An important challenge in the Asia Pacific—exacerbated by population migration—is the rise of drug resistance, specifically of *Plasmodium falciparum* to artemisinin (23) and *Plasmodium vivax* to chloroquine.(24) The Greater Mekong subregion in the Asia Pacific has been the traditional epicenter of antimalarial drug resistance.(25) Modeling suggests that the elimination of *P. falciparum* from this subregion is needed to prevent the spread of artemisinin-resistant parasites to other areas of the world.(26) The threat of chloroquine-resistant *P. vivax* in some parts of the Asia Pacific has sparked concern, however studies to date have been inconclusive. Failing to mitigate these risks today could result in a weaker set of interventions and more resistant parasites tomorrow. (25) Drug resistance networks globally, such as the Worldwide Antimalarial Resistance Network (WWARN, www.wwarn.org) (27) and the World Health Organization, and regionally, such as the newly formed Pacific Malaria Drug Resistance Monitoring Network (28), are monitoring this situation closely.

Plasmodium vivax malaria is the dominant parasite across the APMEN countries. The Asia Pacific region, more specifically South and East Asia, are home to an estimated 52% of all *P. vivax* infections in the world.(29) For example, in China and Sri Lanka, malaria infections caused by *P. vivax* represent, at minimum, 90% of all infections. The predominance of *P. vivax* is an important consideration when designing malaria control and elimination strategies. *Plasmodium vivax* has a persistent liver stage, the hypnozoite, which makes it less susceptible than *P. falciparum* to control and elimination efforts. This liver stage can trigger relapses of infection, most commonly within a month, but relapses can occur years later. *Plasmodium vivax* infections are often asymptomatic or cause mild symptoms. This means they often remain undiagnosed and untreated, resulting in long periods where the infection can be passed on to other mosquitoes.

The effective treatment for the dormant liver stage of *P. vivax* is primaquine. This drug has challenges for drug treatment adherence because of the length of the treatment (14 days) and the bitterness of the tablet. Primaquine can also have severe side effects. It may cause haemolysis in patients with an underlying deficiency of glucose-6-phosphate dehydrogenase (G6PD), an inherited blood disorder. Currently, no easy to use point-of-care test for G6PD deficiency exists. Therefore, in populations that have a high risk of this genetic disorder, primaquine is not used, allowing the liver stage of *P. vivax* malaria to be a reservoir of infection, and slowing the march towards elimination. In order for *P. vivax* to be eliminated, an alternative to the 14-day treatment of primaquine must be found. Working to address this issue is a collaboration of researchers known as the APMEN Vivax Working Group.(12)

With an awareness of the challenges that lie ahead, and the knowledge of historical and recent success stories bolstering them, the 11 countries that form the Asia Pacific Malaria Elimination Network are striving to progressively eliminate malaria. The *Atlas* seeks to establish a visual baseline from which to measure progress towards elimination in the region. We show for the first time country-level maps of the likelihood of transmission for both *P. falciparum* and *P. vivax*, maps of human population density, and maps of probable mosquito vector occurrence, all supported by malariometric and socioeconomic indicators for context. Although the challenges faced by the region are significant, progress toward elimination is inevitable with the energy and commitment of the malaria programs and the cohesive Network of the APMEN countries.

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