REVIEW OF INDEPENDENT EVIDENCE SUPPORTING VECTOR CONTROL ACTIVITIES

Prevention of diseases spread by mosquitoes
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Foreward

This background document provides an overview of vector-borne diseases, their agents of transmission and prevention using recommended practices for vector control. These practices are supported by published evidence that is herein reviewed.

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# Abbreviations

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<tr>
<td>AFRO</td>
<td>WHO Africa Regional Office</td>
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<tr>
<td>cRCT</td>
<td>Cluster randomized control trial</td>
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<td>CBI</td>
<td>Community-based interventions</td>
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<td>DENV</td>
<td>Dengue virus</td>
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<tr>
<td>IEC</td>
<td>Information, education and communication</td>
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<tr>
<td>ITC</td>
<td>Insecticide-treated curtain</td>
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<tr>
<td>ITN</td>
<td>Insecticide-treated bed net</td>
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<tr>
<td>IRS</td>
<td>Indoor Residual Spraying</td>
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<td>IVM</td>
<td>Integrated Vector Management</td>
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<tr>
<td>JEV</td>
<td>Japanese encephalitis virus</td>
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<td>LLIN</td>
<td>Long-lasting insecticidal nets</td>
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<tr>
<td>NTD</td>
<td>Neglected tropical disease</td>
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<td>PAHO</td>
<td>Pan American Health Organization</td>
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<td>WNV</td>
<td>West Nile virus</td>
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<tr>
<td>YFV</td>
<td>Yellow fever virus</td>
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</table>
Overview: A global rise in vector borne diseases

Globally, every year, there are more than 1 billion cases and over 1 million deaths from vector borne diseases such as malaria, dengue, schistosomiasis, human African trypanosomiasis, leishmaniasis, Chagas disease, yellow fever, Japanese encephalitis and onchocerciasis.¹

Vector borne diseases, i.e., those caused by pathogens and parasites in human populations spread by other organisms (vectors), account for over 17 per cent of all infectious diseases.² One sixth of the illness and disability suffered worldwide is due to vector borne diseases, and more than half the world’s population is currently estimated to be at risk of these diseases. While impressive gains have been made against malaria since 2000, and malaria mortality rates have fallen by 62 per cent globally, there is still much to be done. In 2015, there were still an estimated 212 million cases of malaria and 429,000 deaths, 70 per cent of these in children under five.³

However, the burden of many other vector borne diseases is increasing. Environmental changes are causing an increase in the number and spread of many vectors worldwide.⁴ Dengue in particular is emerging as a serious public health concern. In 2012, it ranked as the most important mosquito-borne viral disease with epidemic potential in the world. There has been a thirtyfold increase in cases during the past 50 years, and its human and economic costs are staggering.⁵ The primary vector for dengue, the *Aedes aegypti* mosquito, recently transmitted chikungunya and Zika viruses in the Caribbean islands.

Since 2014, *Aedes* vectors have caused major outbreaks of dengue, chikungunya and yellow fever that have claimed lives and overwhelmed health systems in many countries. Zika virus and its complications have directly impacted children and families resulting in social and economic disruption. The median cost of an integrated vector control programme was reported to be $48 per household in Girardot (Colombia) including the cost of water container covers, insecticide-treated curtains, selected use of larvicides and community education. While this is a seemingly high cost for integrated vector control, this is quite low
when compared to the economic burden of care for dengue disease in Colombia estimated at $292 per patient for ambulatory cases and $1,975 for severe dengue cases.6

Rapid, unmanaged urbanization in tropical and subtropical cities renders large populations at risk of the emergence and expansion of diseases spread by mosquitoes.7 It is therefore reasonable to expect new vector borne diseases to emerge and further intensification of those that are closely associated with urbanization, particularly viral diseases transmitted by Aedes mosquitoes and pathogens that may be transmitted by the Culex mosquito species. As a result of this unpredictability, there is a critical need for adaptive and sustained approaches that reduce disease burden by linking mosquito monitoring indicators with disease prevalence and targeting control to prevent pathogen transmission by vectors.

While UNICEF is already actively communicating the risks of these diseases to communities, and advocating for governmental action in countries when outbreaks occur, its role and level of engagement is tempered by priorities and existing capacities. An expanded cross-sectoral role in vector control across a diverse range of activities will be driven by the evidence of effectiveness presented in this review and adapted to the local context.

Review methodology

Over 200 references,1 including three major reviews and meta-analyses published since 2015, were reviewed and analysed to confirm which approaches do and do not work.8,9,10 Table A provides a summary of the findings. Of the 27 studies having the country identified in the publication title, 40 per cent came from low-income countries, 7 per cent from low-mid-income, 30 per cent from mid-upper-income, and 22 per cent from high-income countries. There were 35 other publications included in the review, specifically investigating some aspect of vector control, which did not specify country or origin or covered multiple countries.

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### Table A. Application of evidence-based interventions for integrated vector control

<table>
<thead>
<tr>
<th>INTERVENTION</th>
<th>AEDES Rural</th>
<th>AEDES Urban</th>
<th>ANOPHELES Rural</th>
<th>ANOPHELES Urban</th>
<th>CULEX Rural</th>
<th>CULEX Urban</th>
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<tbody>
<tr>
<td><strong>1. Surveillance</strong></td>
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<td>Identification</td>
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<td><strong>2. Larval Control</strong></td>
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<td>Water storage container manipulation (lids, polystyrene beads)</td>
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<td>Container treatment (chemical or biological)</td>
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<td>Community-based campaigns (education, source reduction)</td>
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<td><strong>3. Adult Control</strong></td>
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<td>House screening</td>
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<td>Insecticide-treated curtains</td>
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<td><strong>4. Environmental management</strong></td>
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<td>Waste container removal (tires)</td>
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<td>Fill potholes, areas of standing water</td>
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<td>Bed nets</td>
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- **Red**: Intervention is not expected to reduce entomological indicators
- **Green**: Intervention will partially impact entomological indicators
- **Light Green**: Intervention is expected to reduce entomological indicators and impact disease
- **Yellow**: Intervention performance has been variable, influenced by local conditions and species
- **Orange**: Intervention will have limited/no effect on entomological indicators

Colour scale based upon interpretation of the following references: Ballenger-Browning 2009[207], Fasulo 2005[246], Heintze 2007[164], Quintero 2015[194], Sommerfeld 2012[131].
Mosquito-borne diseases

It is not practical to condense all the most current literature covering biology, control and impact for all vectors and the diseases they transmit into one document. The list would include ticks, flies, sandflies, fleas, triatomine bugs and freshwater aquatic snails. As mosquitoes are the best known carriers of diseases of greatest risk for children, this document focuses on vector control for the most notorious genera of disease-transmitting mosquitoes: *Anopheles*, *Aedes* and *Culex*. There are approximately 3,500 species of mosquitoes grouped into 41 genera (*Anopheles*, *Aedes* and *Culex* among others). Mosquitoes are one of the deadliest animals in the world, some having the ability to carry many different diseases. (For the other vectors, readers are referred to online sources for specific details on one species or another.)

**Chikungunya, dengue, yellow fever, and Zika** are related viruses primarily transmitted by *Aedes aegypti* and *Aedes albopictus* mosquitoes. The manifestations of the diseases vary but each is potentially lethal or permanently debilitating. According to the World Health Organization (WHO), the estimated annual number of cases worldwide as of 2016 is 96 million for dengue; 130,000 yellow fever cases just in Africa; 693,000 suspected cases of chikungunya; and 500,000 suspected cases of Zika virus reported by Pan American Health Organization in Latin America. About half of the world’s population is now at risk. Currently there are more than 100 countries in Southeast Asia, Latin America and the Western Pacific region affected by dengue virus alone. Today, severe dengue has become a leading cause of hospitalization and death among children and adults in these regions.

*Aedes albopictus* and other *Aedes* species are competent vectors experimentally of at least 22 other arboviruses (group of viruses spread by mosquitoes and other arthropods) that have the potential to follow an outbreak surge similar to what happened with Zika including Rift Valley fever virus, Japanese encephalitis virus, Sindbis virus, and dirofilaria. Also West Nile virus and Venezuelan equine encephalitis virus have been isolated from *Aedes aegypti* in the field. Control of *Ae. aegypti* and *Ae. albopictus* substantially reduces the threat of multiple virus diseases simultaneously.ii

**Malaria** is a non-viral, life-threatening disease caused by *Plasmodium* parasites transmitted through the bites of infected female *Anopheles* mosquitoes. Anopheline mosquitoes can also transmit other parasites which cause filariasis, togaviruses, and canine heartworm. Of the approximately 430 *Anopheles* species, there are 30-40 that transmit malaria (i.e., are ‘vectors’i) in nature. No other mosquito genera have been confirmed to transmit malaria. In 2015, 91 countries and territories had ongoing malaria transmission resulting in an estimated 212 million cases. About 3.2 billion people – almost half of the world’s

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ii. “Ae.” refers to the species *Aedes*. 

1. ”vectors” refers to species that are carriers of a disease.

2. ”Ae.” refers to the species *Aedes*. 

3. ”Anophelines” refers to species *Anopheles*. 

4. ”Plasmodium” refers to the genus of parasites that cause malaria.

5. ”toga-virus” refers to a specific group of viruses.
population— are at risk of malaria. In areas with high transmission of malaria, children under 5 are particularly susceptible to infection, illness and death; more than two thirds (70 per cent) of all malaria deaths occur in this age group.

Japanese encephalitis virus (JEV) and West Nile virus (WNV) are viruses spread through bites from infected mosquitoes of the Culex genus. JEV is spread mainly by Culex tritaeniorhynchus and primarily affects children. It is estimated that nearly 68,000 clinical cases of JEV occur globally each year, with approximately 13,600 to 20,400 deaths. WNV is maintained in nature in a mosquito-bird-mosquito transmission cycle by Culex pipiens. Most children infected with WNV have mild, flu-like symptoms that last a few days but others have experienced debilitating conditions.

Culex is a diverse genus having several species that can transmit diseases from wild and domestic animals to humans such as lymphatic filariasis, Rift Valley Fever, avian malaria, St. Louis encephalitis and Western equine encephalitis, and they may be able to vector the Zika virus.

Interventions

Risks of vector borne diseases are increasing rapidly due to unplanned urbanization, increased movement of people and goods, environmental changes and biological challenges such as vectors resistant to insecticides and evolving strains of pathogens. Community-based vector control may require more time and resources than reliance upon conventional institution-based approaches but the investment in an integrated approach may be warranted when compared to the indirect cost for outpatient medical attention.

Aside from direct health benefits, sustained vector control programmes lower the burden of care and support, yield greater productivity and growth, reduce household poverty, increase equity and women’s empowerment and strengthen health systems. The efficacy of any control programme depends on target mosquito biology and behavior, local settings, intervention type, resources and sustainability. Mosquito surveillance is the key to any successful vector control programme. This monitoring provides early warning to mobilize medical and control resources that can contain a disease before outbreak occurs. Local involvement in vector control activities, for example ‘search
and eliminate’ for breeding sites or ‘Hang Up and Keep Up’ net distribution campaigns, increases the likelihood that community-oriented interventions will impact vector indices and lead to a reduction of outbreaks for many vector borne diseases. House screening may be an effective intervention against many vector borne diseases where the context is appropriate. Spatially or temporally targeting existing vector control interventions may be more effective than applying them evenly across different locations and times. Likewise, targeting mosquito life stages other than the adult stage only (larvae and pupae) is more effective than previously thought.

Prevention of malaria outbreaks can be effected by using available vector control tools. Bites from Anopheles mosquitoes that fly at night and rest indoors can be blocked using insecticide-treated bed nets (ITNs). Long-lasting insecticidal nets (LLINs) are the preferred form of ITNs for public health programmes. UNICEF has been a major supporter of this intervention for more than a decade. Their LLIN procurement in 2016 was over 40 million LLINs. Indoor residual spraying (IRS) with insecticides is another powerful way to rapidly reduce malaria transmission. Its full potential is realized when at least 80 per cent of houses in targeted areas are sprayed. Indoor spraying is effective for three to six months, depending on the insecticide formulation used and the type of surface on which it is sprayed. The challenges are twofold: operational complexity and mosquito resistance.

The largest gaps in vector control exist for disease outbreaks caused by Aedes and Culex vectors. The most effective intervention to control disease and protect populations is the elimination of breeding sites for those mosquitoes. This requires sustained and ongoing entomological surveillance, education campaigns, improved housing and schools (screened), urban planning, piped water infrastructure, stagnant water abatement systems, routine waste disposal activities, resource allocation and good governance. Successful vector control strategies not only focus on the residential environment but also on day gathering places such as markets, schools, hospitals, etc. The concept of integrated vector management (IVM) is gaining increasingly broader acceptance for the wide range of diseases spread by these genera. This strategy succeeds because multidisciplinary and multisectoral involvement not only finds and breaks the transmission cycle or eliminates the vectors but also because the social and environmental shortcomings that contribute to vector proliferation are corrected. Community mobilization improves the value of all interventions employed (environmental management, house screening, container covers, larviciding, source reduction, insecticide treated materials, personal protection). Community engagement through improved surveillance, advocacy with municipalities, education and clean-up campaigns is an indispensable, foundational component for any vector control programme.
**Aedes mosquito** behaviour differs markedly from the malaria carrying *Anopheles* mosquito. *Aedes species* (spp.) will bite either outdoors or indoors and primarily during daylight hours. Their eggs resist desiccation and will remain viable for extended dry periods. The proximity of mosquito vector breeding sites to human habitation is a significant risk factor for diseases these species transmit. This is why surveillance is a leading indicator for outbreaks. Prevention and control rely heavily on reducing the number of natural and artificial water-filled container breeding habitats. Probably the most widespread practices to suppress *Aedes* vector populations are clean-up campaigns, typically community-driven and in tandem with education and health promotional campaigns that combine additional approaches such as limiting breeding source access and larviciding. Targeted action towards ‘productive’ container types (i.e., those producing the greatest number of pupae relative to other containers in the area) provides more cost-effective larval control. For immediate protection during outbreaks of dengue, chikungunya, Zika or yellow fever, clothing minimizing skin exposure to the day-biting vectors is advised. Repellents can be applied to exposed skin or to clothing. With the exception of adults or children napping during the day where a net might provide some protection, LLINs are not a practical prevention technology for viruses spread by *Aedes* vectors.

In a dengue emergency in Taiwan the number of cases dropped from 32 to a single case per week within four weeks after extensive control measures that included community engagement, larviciding and adult insecticide spraying were initiated. In a multi-country study in Central America, the palette of community interventions reduced risk of infection in children by 30 per cent in Nicaragua and Mexico.

Das et al., (2014) systematically reviewed 62 studies on community-based interventions (CBI) for prevention of non-helminthic infections, of which 17 were on dengue control. CBI for dengue preventive measures (*Aedes* control) significantly reduced dengue positive serostatus by 70 per cent. Community education alone did not have a significant impact. The conclusion was that community delivered interventions may achieve wider coverage and sustained community acceptance by combining interventions having a more rapid and sustainable effect compared to individual interventions. They recommended that a major component of CBI should always come from the community itself as success depends on community structures, customs, beliefs and values.

The findings of Heintze et al., (2007) in their review of the 11 out of 1091 studies that met Cochrane evaluation criteria, suggest community-based control strategies, in addition to or together with biological and chemical vector control

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iii. A systematic review that attempts to identify, appraise and synthesize all the empirical evidence meeting pre-specified eligibility criteria to answer a given research question. Researchers conducting systematic reviews use explicit methods aimed at minimizing bias, in order to produce more reliable findings that can be used to inform decision making.
tools, are able to reduce classical *Aedes* larval indices. Reviewed studies conducted in Thailand and Viet Nam provided information regarding reduction of vector density and disease transmission (estimated by reported/reconfirmed dengue cases or seroconversion (point when antibodies are detectable)). These studies also suggest that coordinated involvement of local health services, trained vector control personnel, civil authorities and the community could contribute to converting information into practice and encourage communities to take over prevention and control measures. This underlines the importance of intersectoral cooperation.

*Culex species (spp.)* breeding habits differ from either *Anopheles* or *Aedes*, in general (there are over 1,000 species of *Culex*, so overlap is bound to occur). They need to lay eggs in water, larvae thrive in water having high organic content, pupae must breathe at the surface, and adults are strong flyers and often favour animals for taking blood. The complexity of characteristics requires an integrated vector control programme applied over a wide area approach to achieve disease prevention (West Nile and various forms of encephalitis). Useful interventions include source reduction through environmental manipulation and the use of personal protection such as clothing and repellents. Larval density reduction using larvicides, biologicals and surface films can be effective under certain conditions. *Culex* spp. exhibits considerable tolerance to pyrethroids, the only class of chemistry used on nets. However, LLINs may provide limited mechanical protection against *Culex* vectors of lymphatic filariasis. Note that the disease is vectored by a number of mosquito species, including *Anopheles*, so LLIN would not be a core defense technology.

**Conclusion**

The foundation of any vector control programme requires resources, regulatory and political support from national and municipal governments, and community engagement with strong advocacy for action. The success and sustainability of vector control interventions depend on harnessing available social capital and resources at the municipal and community level. Local knowledge and skills (cultural capital) can be harnessed to support effective, sustainable, locally appropriate and feasible vector control solutions.

The Partnership for Dengue Control convened a meeting of 60 international experts in 2016 as a follow-up to a previous meeting that reviewed the relative effectiveness of existing vector control interventions. Their opinions are reflected in Table B and summarize the currently available options, the vectors for which they are most appropriate, and challenges for sustained use.
<table>
<thead>
<tr>
<th>Intervention</th>
<th>Mosquito (An, Ae, Cx)*</th>
<th>Best circumstances</th>
<th>Challenges where already in use</th>
<th>Challenges in new contexts</th>
</tr>
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<tbody>
<tr>
<td><strong>Larval control</strong> (no intervention stands alone; all rely upon community action)</td>
<td>An+ Ae+++ Cx++</td>
<td>Community awareness &amp; participation in Aedes and Culex control; knowledge of 'super producer’ sites; routine entomological surveillance</td>
<td>Training, maintenance, time of implementation (i.e., surveillance gaps); case location</td>
<td>Organization; reduced labour needs with targeted delivery; local production</td>
</tr>
<tr>
<td>1. Container manipulation (lids, polystyrene beads)</td>
<td>Ae+++ Cx+</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Container treatment (chemical)</td>
<td>Ae+++ Cx++</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Container treatment (biologicals)</td>
<td>Ae+++ Cx++</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>a. Larvivorous fish</td>
<td>Ae++</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>b. Copepods</td>
<td>Ae++</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Community-based campaigns (education, source reduction, net distribution)</td>
<td>An++ Ae+++ Cx+</td>
<td>Indicators for people to follow; community awareness &amp; interest; cooperative local government; no tall apartment buildings</td>
<td>Sustainability of interest; time of implementation in relation to epidemics (i.e., surveillance gaps)</td>
<td>Organization</td>
</tr>
<tr>
<td>5. Environmental manipulation and source management (waste container removal)</td>
<td>Ae+++ Cx+++</td>
<td>Settings with infrastructure to support system; Community acceptance;</td>
<td>Settings without infrastructure to support system; organized commitment</td>
<td>Organization</td>
</tr>
</tbody>
</table>
### Table B. Control interventions applied to specific vector species

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Mosquito (An, Ae, Cx)*</th>
<th>Best circumstances</th>
<th>Challenges where already in use</th>
<th>Challenges in new contexts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Adult control</strong> (WHO does not support fogging, ULV)</td>
<td>An+++ Ae++ Cx+</td>
<td>Settings with infrastructure to support system; Community acceptance; Uniform housing construction</td>
<td>Settings without infrastructure to support system; organized commitment</td>
<td>Organization + consumer product market</td>
</tr>
<tr>
<td>1. House screening</td>
<td>An+++ Ae+++ Cx+</td>
<td>Indoor biting; organized campaign; early-warning; starting in high-risk areas</td>
<td>Acceptance; ability to apply coverage completely; SP** resistance, laborious training, maintenance, time of implementation (i.e., surveillance gaps)</td>
<td>Organization; Improved residual formulations; non-SP formulations</td>
</tr>
<tr>
<td>2. Insecticide-treated curtains</td>
<td>An+ Ae++</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Indoor residual spray</td>
<td>An+++ Ae+ Cx-</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Personal protection</strong></td>
<td>An+++ Ae+ Cx++</td>
<td>During epidemics; population groups with discretionary spending</td>
<td>User acceptability; willingness to pay (WTP); Efficacy against indoor pest mosquitoes: eg., <em>Culex</em></td>
<td>Organization + consumer product market; Increased duration</td>
</tr>
<tr>
<td>1. DEET, Picaridin</td>
<td>Ae++ Cx+++</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. Consumer products</td>
<td>Ae++ Cx+++</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Bed nets</td>
<td>An+++ Ae+ Cx-</td>
<td>For quarantine purposes; persons who sleep indoors during the day (children); starting in high-risk areas; indoor biting; night biting</td>
<td>User acceptability; willingness to pay (WTP)</td>
<td>Organization + consumer product market</td>
</tr>
</tbody>
</table>

An = *Anopheles*;  
Ae = *Aedes*;  
Cx = *Culex*  
**SP = synthetic pyrethroids**  
+++ highly useful;  
++ useful;  
+ potentially useful in some circumstances;  
- currently no evidence of usefulness
Key facts

- Vector borne diseases (VBDs) account for more than 17 per cent of all infectious diseases, causing more than 1 billion cases and more than 1 million deaths from VBDs annually.

- VBD impact is on the rise. WHO estimates that rising global temperatures, as well as altered precipitation and humidity linked to climate change, could significantly alter VBDs and their effect on human populations—making epidemics more difficult to predict and control. The changes in VBDs would likely occur as both short-term epidemics and long-term gradual changes in disease trends.

- More than 2.5 billion people in over 100 countries are at risk of contracting dengue alone.

- Malaria causes more than 400,000 deaths every year globally, most of them children under 5 years of age.

- Other diseases such as Chagas disease, leishmaniasis and schistosomiasis affect hundreds of millions of people worldwide.

- Many of these diseases are preventable through informed protective measures.

Overview

Except where otherwise indicated, the information presented was extracted from [http://www.who.int/mediacentre/factsheets/fs387/en/](http://www.who.int/mediacentre/factsheets/fs387/en/) Global Vector Control Response 2017-2030, Draft 3.1, and various factsheets prepared by US Centers for Disease Control (CDC), National Center for Emerging and Zoonotic Infectious Diseases (NCEZID), Division of Vector-Borne Diseases (DVBD) found at [http://www.cdc.gov/ncezid/dvbd/index.html](http://www.cdc.gov/ncezid/dvbd/index.html).

Vector borne diseases account for over 17 per cent of all infectious diseases. These diseases are illnesses caused by pathogens and parasites in human populations spread by other organisms (vectors). Every year there are more than 1 billion cases and over 1 million deaths from vector borne diseases such as malaria, dengue, schistosomiasis, human African trypanosomiasis, leishmaniasis, Chagas disease, yellow fever, Japanese encephalitis and onchocerciasis, globally. Distribution of these diseases is determined by a complex dynamic of environmental and social factors.

Social, demographic and environmental factors have altered transmission patterns and intensified the geographical spread, re-emergence of diseases and the extension of transmission seasons. In particular, unplanned urbanization and lack of regular water supply or solid waste disposal can render large populations in towns...
and cities at risk of viral diseases spread by mosquitoes. Enhanced global travel and trade, combined with environmental factors such as altered land use patterns and climate change, may also have an effect. Together, such factors influence the reach of vector populations and the transmission patterns of the disease-causing pathogens.

While impressive gains have been made against malaria, onchocerciasis, lymphatic filariasis and Chagas disease, the burden of many other vector borne diseases has increased in recent years. Since 2014, major outbreaks of dengue, malaria, chikungunya and yellow fever have afflicted populations, claimed lives and overwhelmed health systems in many countries. Zika virus and its complications have directly impacted individuals and families, and caused social and economic disruption.

Globalization of travel and trade, unplanned urbanization and environmental challenges such as climate change are having a significant impact on disease transmission in recent years. Some diseases, such as dengue, chikungunya and West Nile virus, are emerging in countries where they were previously unknown. Changes in agricultural practices due to variations in temperature and rainfall can affect the transmission of vector borne diseases. It is reasonable to expect the emergence of new vector borne diseases and further intensification of those viral diseases transmitted by Aedes mosquitoes that are closely associated with urbanization. Also of concern are pathogens that may be transmitted by Culex mosquito species and other arthropods.

This complexity and unpredictability underscores the critical need for adaptive and sustained approaches to prevent and reduce pathogen transmission to reduce disease burden.

**UNICEF’s role in vector control**

The impact of vector borne diseases on children can be devastating in areas where they have no natural immunity. UNICEF has been actively communicating the risks of diseases such as Zika, dengue, chikungunya, yellow fever, and malaria to communities and advocating for governmental action in countries when outbreaks occur. UNICEF’s role and level of engagement in vector control is tempered by priorities and existing capacities. An expanded cross-sectoral role in vector control across a diverse range of activities will be driven by the evidence of their effectiveness presented in this review and adapted to the local context.

**Main vectors and the diseases they transmit**

Vectors are living organisms that can transmit infectious diseases between humans or from animals to humans. Many of these vectors are bloodsucking insects, which ingest disease-producing microorganisms during a blood meal from an infected host (human or animal) and later inject it into a new host during their subsequent blood meal.

Mosquitoes are the best known disease vector. Others include ticks, flies, sandflies, fleas, triatomine bugs and some freshwater aquatic snails.
It is not practical to condense the most current literature covering biology, control and impact for all vectors and the diseases they transmit into a single useable document. Vector control, in the context presented here, will pertain to the most notorious genera of mosquitoes that transmit diseases of great risk for children. For the rest, readers are referred to online sources for specific details on one species or another.

**Mosquito-borne diseases**

Mosquitoes are one of the deadliest animals in the world. Their ability to carry and spread disease to humans in all inhabited geographic regions causes millions of deaths every year (Table 3). In 2015, malaria alone caused 438,000 deaths. Zika, dengue, chikungunya and yellow fever are all transmitted to humans by the *Aedes aegypti* mosquito. More than half of the world’s population lives in areas where this mosquito species is present in the same way that at least half of the world’s population is at risk for malaria. Sustained mosquito control efforts can help prevent outbreaks from these diseases.

Mosquito-borne flaviviruses are transmitted in nature in one or more distinct or overlapping cycles that include a mosquito vector, generally *Aedes* spp. mosquitoes for yellow fever virus (YFV) and dengue virus (DENV) and *Culex* spp. mosquitoes for Japanese encephalitis virus (JEV) and West Nile virus (WNV), and a mammalian or avian host.\(^{30}\) Many species of mosquitoes have the ability to carry multiple diseases.

Previous studies suggest JEV introduction into new geographic areas is possible where there are competent mosquitoes and susceptible vertebrate hosts. The introduction of JEV into Australia and WNV into the United States exemplify how rapidly JEV-serocomplex flaviviruses can establish in geographic regions where the competent vectors are present and the vertebrate hosts are immunologically naïve.\(^ {31}\) Given the widespread presence of the anopheline vector, malaria re-introduction is thus always a possibility even in countries that have eliminated the disease. Preventing the re-introduction through enhanced disease surveillance is a pillar of the WHO global technical strategy for malaria.

**Table 1. Main arthropod vectors and diseases transmitted**

<table>
<thead>
<tr>
<th>Mosquitoes</th>
<th>Sandflies</th>
<th>Triatome bugs</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aedes</em></td>
<td>Leishmaniasis</td>
<td>Chagas disease</td>
</tr>
<tr>
<td>Chikungunya</td>
<td>Sandfly fever</td>
<td>(American trypanosomiasis)</td>
</tr>
<tr>
<td>Dengue fever</td>
<td>(phlebotomus fever)</td>
<td></td>
</tr>
<tr>
<td>Rift Valley fever</td>
<td></td>
<td></td>
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<tr>
<td>Yellow fever</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Zika</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Anopheles</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Malaria</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Culex</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Japanese encephalitis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lymphatic filariasis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>West Nile fever</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Ticks</em></td>
<td></td>
<td></td>
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<tr>
<td>Crimean-Congo haemorrhagic fever</td>
<td></td>
<td></td>
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<tr>
<td>Lyme disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Relapsing fever (borreliosis)</td>
<td></td>
<td></td>
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<tr>
<td>Rickettsial diseases</td>
<td></td>
<td></td>
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<tr>
<td>(spotted fever and Q fever)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tick-borne encephalitis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tularaemia</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Sandflies</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Leishmaniasis</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Triatome bugs</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chagas disease</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(American trypanosomiasis)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Tsetse flies</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sleeping sickness</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(African trypanosomiasis)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Fleas</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plague</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(transmitted by fleas from rats to humans)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rickettsiosis</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Black flies</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Onchocerciasis (river blindness)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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\(^{30}\) Many species of mosquitoes have the ability to carry multiple diseases.

\(^{31}\) Given the widespread presence of the anopheline vector, malaria re-introduction is thus always a possibility even in countries that have eliminated the disease. Preventing the re-introduction through enhanced disease surveillance is a pillar of the WHO global technical strategy for malaria.
## Table 2. Mosquitoes and diseases carried

<table>
<thead>
<tr>
<th>Disease</th>
<th>Mosquito genus</th>
<th>Burden (estimated)</th>
<th>Global distribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chikungunya</td>
<td><em>Aedes</em></td>
<td>693,000 suspected cases</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Dengue</td>
<td><em>Aedes</em></td>
<td>96 million for dengue</td>
<td>Worldwide</td>
</tr>
<tr>
<td>Japanese encephalitis virus</td>
<td><em>Culex</em></td>
<td>67,900 estimated cases</td>
<td>Asia, Australia, western Pacific</td>
</tr>
<tr>
<td>Lymphatic filariasis</td>
<td><em>Culex &amp; Anopheles</em></td>
<td>119 million people infected for life</td>
<td>Primarily India, SEA, Africa (84 endemic cos)</td>
</tr>
<tr>
<td>Malaria</td>
<td><em>Anopheles</em></td>
<td>214 million cases annually</td>
<td>Worldwide with 90% of cases in Africa</td>
</tr>
<tr>
<td>West Nile virus</td>
<td><em>Culex &amp; Aedes</em></td>
<td>2,038 cases in US, 2016</td>
<td>US, Africa, EU, Asia (along bird migration routes)</td>
</tr>
<tr>
<td>Yellow fever</td>
<td><em>Aedes</em></td>
<td>130,000 yellow fever cases just in AFRO</td>
<td>Mostly Africa but potential for global distribution</td>
</tr>
<tr>
<td>Zika</td>
<td><em>Aedes &amp; Culex (suspected)</em></td>
<td>500,000 suspected cases just in PAHO</td>
<td>Mostly seen in Latin America but potential for worldwide</td>
</tr>
</tbody>
</table>

## Table 3. Mosquito vector borne diseases geographically

### CENTRAL & SOUTH AMERICA
- Malaria
- Chikungunya virus
- Dengue fever
- Yellow fever
- West Nile virus
- Zika virus

### NORTH AMERICA
- West Nile virus
- Zika virus
- Eastern equine encephalitis

### SUB-SAHARAN AFRICA
- Malaria
- Chikungunya virus
- Dengue fever
- Yellow fever
- Lymphatic filariasis
- West Nile virus

### NORTH AFRICA
- Malaria
- Chikungunya virus
- West Nile virus

### ASIA
- Malaria
- Chikungunya virus
- Dengue fever
- Japanese encephalitis
- Lymphatic filariasis

### EUROPE
- Malaria
- Chikungunya virus
- West Nile virus
- Yellow fever

### OCEANIA
- Malaria
- Chikungunya virus
- Dengue fever
- Japanese encephalitis
- Lymphatic filariasis
Chikungunya Features:

- Chikungunya is a viral disease transmitted to humans by infected mosquitoes. It causes fever and severe joint pain. Other symptoms include muscle pain, headache, nausea, fatigue and rash.
- Joint pain is often debilitating and can vary in duration.
- The disease shares some clinical signs with dengue, and can be misdiagnosed in areas where dengue is common.
- There is no cure for the disease. Treatment is focused on relieving the symptoms.
- The proximity of mosquito breeding sites to human habitation is a significant risk factor for chikungunya.
- The disease occurs in Africa, Asia and the Indian subcontinent. In recent decades mosquito vectors of chikungunya have spread to Europe and the Americas. In 2007, disease transmission was reported for the first time in a localized outbreak in north-eastern Italy. Outbreaks have since been recorded in France and Croatia.

Where found:
Chikungunya has been identified in over 60 countries in Asia, Africa, Europe and the Americas.

Impact on children:
Vertical transmission of disease from mother to child has been documented. Clinical manifestations are very variable, from asymptomatic illness to severe debilitating disease. Children are among the group at maximum risk for severe manifestations of the disease and some clinical features in this group are distinct from those seen in adults. Common clinical features include: abrupt onset high grade fever, skin rashes, minor haemorrhagic manifestations, arthralgia/ arthritis, lymphadenopathy, conjunctival injection, swelling of eyelids and pharyngitis. Unusual clinical features include: neurological manifestations including seizures, altered level of consciousness, blindness due to retrobulbar neuritis and acute flaccid paralysis. Watery stools may be seen in infants.

Transmission:
The virus is transmitted from human to human by the bites of infected female mosquitoes. After the bite of an infected mosquito, onset of illness occurs usually between four to eight days but can range from two to 12 days. For a more complete discussion of the transmission cycle and viral replication factors, refer to Solignat et al.33

Vectors:
Most commonly, the mosquitoes involved are Aedes aegypti and Aedes albopictus, two species which can also transmit other mosquito-borne viruses, including dengue. These mosquitoes can be found biting throughout daylight hours, though there may be peaks of activity in the early morning and late afternoon. Both species are found biting outdoors, but Ae. aegypti will also readily feed indoors.
Whereas *Ae. aegypti* is confined within the tropics and subtropics, *Ae. albopictus* also occurs in temperate and even cold temperate regions. In recent decades, *Ae. albopictus* has spread from Asia to become established in areas of Africa, Europe and the Americas. In Africa, several other mosquito vectors have been implicated in disease transmission, including species of the *A. furcifer-taylori* group and *A. luteocephalus*. There is evidence that some animals, including non-primates, rodents, birds and small mammals, may act as reservoirs.

### Dengue (DENV)

**Features:**

- Dengue is a mosquito-borne viral infection.
- The infection causes flu-like illness, and occasionally develops into a potentially lethal complication called severe dengue.
- The global incidence of dengue has grown dramatically in recent decades. About half of the world’s population is now at risk.
- Dengue is found in tropical and subtropical climates worldwide, mostly in urban and semi-urban areas.
- Severe dengue is a leading cause of serious illness and death among children in some Asian and Latin American countries.
- There is no specific treatment for dengue or severe dengue, but early detection and access to proper medical care lowers fatality rates below 1 per cent.
- There are four distinct, but closely related, serotypes of the virus that cause dengue (DEN-1, DEN-2, DEN-3 and DEN-4). Recovery from infection by one provides lifelong immunity against that particular serotype. However, cross-immunity to the other serotypes after recovery is only partial and temporary. Subsequent infections by other serotypes increase the risk of developing severe dengue.
- Dengue prevention and control depends on effective vector control measures.
- A dengue vaccine has been licensed by several National Regulatory Authorities for use in people 9-45 years of age living in endemic settings.
Where found:

Dengue is a mosquito-borne viral disease that has rapidly spread in all regions of WHO in recent years. In the 1970s, only nine countries were considered endemic for DENV. Now there are more than 100 countries in Southeast Asia, Latin America and the Western Pacific region affected by DENV. Dengue is widespread throughout the tropics, with local variations in risk influenced by rainfall, temperature and unplanned rapid urbanization. Severe dengue (also known as dengue haemorrhagic fever) was first recognized in the 1950s during dengue epidemics in the Philippines and Thailand.

The incidence of dengue has grown dramatically around the world in recent decades. The actual numbers of dengue cases are underreported and many cases are misclassified. One recent estimate indicates 390 million dengue infections per year (range of 284–528 million), of which 96 million (67–136 million) manifest clinically (with any severity of disease). Another study, of the prevalence of dengue, estimates that 3.9 billion people, in 128 countries, are at risk of infection with dengue viruses.

Impact on children:

Today, severe dengue affects most Asian and Latin American countries and has become a leading cause of hospitalization and death among children and adults in these regions. From 1985 to 2005, Nicaragua reported endemic dengue. The major burden of disease in Nicaragua was in infants and children 5 to 9 years of age. It was stated that at this age in children a peak in cases can be expected in a country that has been endemic for dengue for more than 15 years. Countries with a shorter or nonendemic history of dengue circulation report cases principally in the adolescent and adult population.

Transmission:

Dengue virus is transmitted by female mosquitoes mainly of the species Aedes aegypti and, to a lesser extent, Ae. albopictus. These mosquitoes may also transmit chikungunya, yellow fever and Zika infection.

The virus is transmitted to humans through the bites of infected female mosquitoes. After virus incubation for four to 10 days, an infected mosquito is capable of transmitting the virus for the rest of its life. Infected symptomatic or asymptomatic humans are the main carriers and multipliers of the virus, serving as a source of the virus for uninfected mosquitoes. Patients who are already infected with the dengue virus can transmit the infection (for four to five days; maximum 12) via Aedes mosquitoes after their first symptoms appear. For a more complete description of the transmission cycle refer to WHO 2009.

Vectors:

The Aedes aegypti mosquito is the primary vector of dengue. The Aedes aegypti mosquito lives in urban habitats and breeds mostly in man-made containers. Unlike other mosquitoes Ae. aegypti is a day-time feeder; its peak biting periods are early in the morning and in the evening before dusk. Female Ae. aegypti bites multiple people during each feeding period.

Aedes albopictus, a secondary dengue vector in Asia, has spread to North America and more than 25 countries in the European Region, largely due to the international trade in used tyres (a breeding habitat) and other goods (e.g., lucky bamboo). Ae. albopictus is highly adaptive and can therefore survive in the cooler temperate regions of Europe. Its spread is due to its tolerance to temperatures below freezing, its hibernation and ability to shelter in microhabitats.
Yellow fever

Features:

- Yellow fever is an acute viral haemorrhagic disease transmitted by infected mosquitoes. The ‘yellow’ in the name refers to the jaundice that affects some patients.

- Symptoms of yellow fever include fever, headache, jaundice, muscle pain, nausea, vomiting and fatigue.

- A small proportion of patients who contract the virus develop severe symptoms and approximately half of those die within seven to 10 days.

- The virus is endemic in tropical areas of Africa and Central and South America.

- Since the launch of the Yellow Fever Initiative in 2006, significant progress in combatting the disease has been made in West Africa and more than 105 million people have been vaccinated in mass campaigns. No outbreaks of yellow fever were reported in West Africa during 2015.

- Large epidemics of yellow fever occur when infected people introduce the virus into heavily populated areas with high mosquito density and where most people have little or no immunity, due to lack of vaccination. In these conditions, infected mosquitoes transmit the virus from person to person.

- Yellow fever is prevented by an extremely effective vaccine, which is safe and affordable. A single dose of yellow fever vaccine is sufficient to confer sustained immunity and life-long protection against yellow fever disease and a booster dose of the vaccine is not needed. The vaccine provides effective immunity within 30 days for 99 per cent of persons vaccinated.

- Good supportive treatment in hospitals improves survival rates. There is currently no specific anti-viral drug for yellow fever.
Where found:
There are 34 countries in Africa and 13 in Central and South America that are either endemic for, or have regions that are endemic for, yellow fever. A modelling study based on African data sources estimated the burden of yellow fever during 2013 was 84,000–170,000 severe cases and 29,000–60,000 deaths.

Impact on children:
In Africa, natural immunity accumulates with age, and thus, infants and children are at highest risk for disease. In South America, yellow fever occurs most frequently in unimmunized young men who are exposed to mosquito vectors through their work in forested areas.

Transmission:
The yellow fever virus is an arbovirus of the flavivirus genus and is transmitted by mosquitoes, belonging to Aedes and Haemagogus species. The different mosquito species live in different habitats: some breed around houses (domestic), others in the jungle (wild), and some in both habitats (semi-domestic). There are three types of transmission cycles:

- Sylvatic (or jungle) yellow fever: In tropical rainforests, monkeys, which are the primary reservoir of yellow fever, are bitten by wild mosquitoes which pass the virus on to other monkeys. Occasionally humans working or travelling in the forest are bitten by infected mosquitoes and develop yellow fever.

- Intermediate yellow fever: In this type of transmission, semi-domestic mosquitoes (those that breed both in the wild and around households) infect both monkeys and people. Increased contact between people and infected mosquitoes leads to increased transmission and many separate villages in an area can develop outbreaks at the same time. This is the most common type of outbreak in Africa.

- Urban yellow fever: Large epidemics occur when infected people introduce the virus into heavily populated areas with high mosquito density and where most people have little or no immunity, due to lack of vaccination. In these conditions, infected mosquitoes transmit the virus from person to person.

Greater than 90 per cent of cases occur in sub-Saharan Africa, where the virus exists in a jungle cycle featuring Ae. africanus, an urban cycle featuring Ae. aegypti, and an intermediate sylvatic cycle that links the two in which tree-hole breeding mosquitoes such as Ae. africanus, Ae. bromeliae, Ae. luteocephalus, Ae. furcifer, Ae. metallicus, Ae. oek, Ae. taylori, Ae. vittatus, Ae. simpsoni, and Ae. kenyensis transmit virus to humans and non-human primates. According to Huang (2014), in South America, the jungle cycle is propagated by Haemagogus janthinomys and Sabethes chloropterus mosquitoes and humans and non-human primates, and urban transmission of virus to humans by Ae. aegypti only occurs sporadically.

Vectors:
Yellow fever virus is mainly transmitted through the bite of the yellow fever mosquito Aedes aegypti, but other Aedes mosquitoes (Ae. africanus, Ae. simpsoni, Ae. furcifer, Ae. Luteocephalus) and the tiger mosquito (Aedes albopictus) can also serve as a vector for this virus. Jungle, or sylvatic, yellow fever is transmitted by Haemagogus and other mosquitoes (such as Masoni africana) of the forest canopy (tree-hole breeding mosquitoes). These mosquitoes acquire the virus from viremic primates. The yellow fever virus can also be passed from one mosquito generation to another via mosquito eggs. In rare cases the virus has also been isolated from other arthropod vectors (flies, ticks).
**Zika**

**Features:**
- Zika virus disease is caused by a virus transmitted primarily by Aedes mosquitoes.
- People with Zika virus disease can have symptoms including mild fever, skin rash, conjunctivitis, muscle and joint pain, malaise or headache. These symptoms normally last for two to seven days.
- There is scientific consensus that Zika virus is a cause of microcephaly and Guillain-Barré syndrome. Links to other neurological complications are also being investigated.

**Where found:**

**Table 4. Countries with Zika virus transmission**

<table>
<thead>
<tr>
<th>Widespread transmission*</th>
<th>Sporadic/limited transmission*</th>
<th>Historical transmission*</th>
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<tbody>
<tr>
<td>High risk (39)</td>
<td>Moderate risk (21)</td>
<td>Low risk (16)</td>
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<tr>
<td>American Samoa</td>
<td>Anguilla</td>
<td>Bangladesh</td>
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<tr>
<td>Argentina</td>
<td>Antigua and Barbuda</td>
<td>Cambodia</td>
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<td>Aruba - Netherlands Territory</td>
<td>Bahamas</td>
<td>Cook Islands</td>
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<td>Barbados</td>
<td>Belize</td>
<td>Easter Island (Islanda de Pascua), Chile</td>
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<td>Bolivia</td>
<td>Bonaire, St Eustatius and Saba</td>
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<td>Brazil</td>
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<td>Dominican (Commonwealth)</td>
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<td>Papua New Guinea</td>
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<td>Dominican Republic</td>
<td>Kosrae, Federated States of Micronesia</td>
<td>Samoa</td>
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<td>Ecuador</td>
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<td>Grenada</td>
<td>Sint Maarten - Netherlands Territory</td>
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Table 4. Countries with Zika virus transmission

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<td>Venezuela</td>
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<td>Viet Nam</td>
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* Widespread transmission: Countries/territories/areas with >10 cases vector borne transmission within the last three months.

# Sporadic transmission: Countries/territories/areas with 1-9 cases vector borne transmission within last three months.

+ Historical transmission: Countries/territories/areas with no reported cases within the last 3 months, but evidence of vector borne transmission since 2007.


Impact on children:

Sufficient evidence has accumulated to infer a causal relationship between prenatal Zika virus infection and microcephaly and other severe brain anomalies.44

Based on a systematic review of the literature up to 30 May 2016, WHO has concluded that Zika virus infection during pregnancy is a cause of congenital brain abnormalities, including microcephaly; and that Zika virus is a trigger of Guillain-Barré syndrome. Intense efforts are continuing to investigate the link between Zika virus and a range of neurological disorders, within a rigorous research framework.

Transmission:

Zika virus is primarily transmitted to people through the bite of an infected mosquito from the Aedes genus, mainly *Aedes aegypti* in tropical regions.

Several factors could contribute to the risk of an outbreak:

- High densities of *Ae. aegypti* and *Ae. albopictus* in several countries in the European Region where the mosquitoes are established;
- Favourable ecological and climatic conditions for establishment of *Ae. aegypti* and *Ae. albopictus* in several countries in which the vector is not currently present;
- Numerous infected travelers returning from affected areas, due to high global mobility;
- Sufficient human population density in countries in which *Ae. aegypti* and/or *Ae. albopictus* are currently present or could be established;
- Lack of immunity of the European population to Zika virus disease, due to lack of previous exposure;
• Difficulty detecting local transmission early, as three out of four people infected with Zika virus do not show symptoms.

• Sexual transmission of Zika virus is also possible. Zika virus can be transmitted through sexual intercourse. This is of concern due to an association between Zika virus infection and adverse pregnancy and foetal outcomes. Other modes of transmission such as blood transfusion are being investigated.

**Vectors:**

The primary Aedes species vector of Zika virus worldwide is *Ae. aegypti*, which is responsible for the current outbreak in the Americas. This is the same mosquito that transmits dengue, chikungunya and yellow fever. *Ae. albopictus* has been shown to be able to transmit Zika virus in Africa and in laboratory settings. *Ae. albopictus* is considered to have lower vector capacity than *Ae. aegypti* for transmitting arboviruses (viruses transmitted by insects).

<table>
<thead>
<tr>
<th><strong>Ae. aegypti</strong></th>
<th><strong>Ae. albopictus</strong></th>
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<tbody>
<tr>
<td>bites primarily humans (anthropophilic)</td>
<td>bites primarily wild and domestic animals (zoophilic) but also humans</td>
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<tr>
<td>tends to bite indoors</td>
<td>tends to bite outdoors</td>
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<tr>
<td>feeds multiple times per cycle of egg production</td>
<td>feeds once per cycle of egg production</td>
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Malaria

Features

- Malaria is a life-threatening disease caused by parasites of the genus Plasmodia that are transmitted to people through the bites of infected female Anopheles mosquitoes.
- In 2015, 95 countries and territories had ongoing malaria transmission.
- About 3.2 billion people – almost half of the world’s population – are at risk of malaria.
- Malaria is preventable and curable, and increased efforts, primarily in vector control, are dramatically reducing the malaria burden in many places.
- Between 2000 and 2015, malaria incidence among populations at risk (the rate of new cases) fell by 37 per cent globally. In that same period, malaria death rates among populations at risk fell by 60 per cent globally among all age groups and by 65 per cent among children under 5.
- Sub-Saharan Africa carries a disproportionately high share of the global malaria burden. In 2015, the region was home to 88 per cent of malaria cases and 90 per cent of malaria deaths.
- Children bear a disproportionate share of the risk and a child dies of malaria every two minutes.
- Pregnant women, particularly in their first pregnancies, are also at increased risk for malaria infection due to reduced immunity.

Where found:

In 2015, approximately 3.2 billion people – nearly half of the world’s population – were at risk of malaria. Most malaria cases and deaths occur in sub-Saharan Africa. However, Asia, Latin America, and, to a lesser extent, the Middle East, are also at risk. In 2015, 95 countries and territories had ongoing malaria transmission.

Impact on children:

In areas with high transmission of malaria, children under 5 are particularly susceptible to infection, illness and death; more than two thirds (70 per cent) of all malaria deaths occur in this age group. Between 2000 and 2015, the under-five malaria death rate fell by 65 per cent globally, translating into an estimated 5.9 million child lives saved between 2001 and 2015.

Each year, approximately 125 million women living in malaria-endemic countries throughout the world become pregnant. An estimated 10,000 of these women and 200,000 of their infants die as a result of malaria infection during pregnancy, and severe malarial anaemia cases contribute to more than half of these deaths.
Malaria transmission:
Malaria parasites are spread to people through the bites of infected female Anopheles mosquitoes. There are five parasite species causing malaria in humans, and two of these species – *P. falciparum* and *P. vivax* – pose the greatest threat. *P. ovale* and *P. malariae* have low prevalence and causes milder symptoms than the two other more virulent Plasmodium species. *P. knowlesi* is very rarely found and mostly only in Southeast Asia.

- *P. falciparum* is the most prevalent malaria parasite on the African continent. It is responsible for most malaria-related deaths globally.
- *P. vivax* is the dominant malaria parasite in most countries outside of sub-Saharan Africa.

Transmission also depends on climatic conditions that may affect the number and survival of mosquitoes, such as rainfall patterns, temperature and humidity. In many places, transmission is seasonal, with the peak during and just after the rainy season. Malaria epidemics can occur when climate and other conditions (e.g., mass or forced population movements) suddenly favour transmission in areas where people have little or no immunity to malaria. They can also occur when people with low immunity move into areas with intense malaria transmission, for instance to find work, or as refugees.

Human immunity is another important factor, especially among adults in areas of moderate or intense transmission conditions. Partial immunity is developed over years of exposure, and while it never provides complete protection, it does reduce the risk that malaria infection will cause severe disease. For this reason, most malaria deaths in Africa occur in young children, whereas in areas with less transmission and low immunity, all age groups are at risk. Refer to numerous references online for different aspects that affect malaria transmission, vector competence, and host susceptibility [https://www.cdc.gov/malaria/about/biology/human_factors.html].

Vectors:
In most cases, malaria is transmitted through the bites of female Anopheles mosquitoes. There are more than 400 different species of Anopheles mosquito; around 30 are malaria vectors of major importance. All of the important vector species bite between dusk and dawn. The intensity of transmission depends on factors related to the parasite, the vector, the human host, control measures and the environment.

Transmission is more intense in places where the mosquito lifespan is longer (so that the parasite has time to complete its development inside the mosquito) and where it prefers to bite humans rather than other animals. The long lifespan and strong human-biting habit of the African vector species is the main reason why nearly 90 per cent of the world’s malaria cases are in Africa.
Japanese encephalitis

Features

- JEV is a flavivirus related to dengue, yellow fever and West Nile viruses, and is spread by mosquitoes.
- JEV is the main cause of viral encephalitis in many countries of Asia with an estimated 68,000 clinical cases every year.
- Although symptomatic Japanese encephalitis is rare, the case fatality rate among those with encephalitis can be as high as 30 per cent. Permanent neurologic or psychiatric sequelae can occur in 30 to 50 per cent of those with encephalitis.
- Twenty-four countries in the WHO Southeast Asia and Western Pacific regions have endemic JEV transmission, exposing more than 3 billion people to the risk of infection.
- There is no cure for the disease. Treatment is focused on relieving severe clinical signs and supporting the patient to overcome the infection.
- Safe and effective vaccines are available to prevent Japanese encephalitis. WHO recommends that JE vaccination be integrated into national immunization schedules in all areas where Japanese encephalitis disease is recognized as a public health issue.

Where found:

JEV is the most important cause of viral encephalitis in Asia. It is a mosquito-borne flavivirus, and belongs to the same genus as dengue, yellow fever and West Nile viruses.

Impact on children:

The annual incidence of clinical disease varies both across and within endemic countries, ranging from <1 to >10 per 100,000 population or higher during outbreaks. A literature review estimates nearly 68,000 clinical cases of Japanese encephalitis globally each year, with approximately 13,600 to 20,400 deaths. JE primarily affects children. Most adults in endemic countries have natural immunity after childhood infection, but individuals of any age may be affected.

Transmission:

JEV is transmitted to humans through bites from infected mosquitoes of the *Culex* species (mainly *Culex tritaeniorhynchus*). Humans, once infected, do not develop sufficient viraemia to infect feeding mosquitoes. The virus exists in a transmission cycle between mosquitoes, pigs and/or water birds (enzootic cycle). The disease is predominantly found in rural and periurban settings, where humans live in closer proximity to these vertebrate hosts.

In most temperate areas of Asia, JEV is transmitted mainly during the warm season, when large epidemics can occur. In the tropics and subtropics, transmission can occur year-round but often intensifies during the rainy season and pre-harvest period in rice-cultivating regions.

Vectors:

There are approximately 3 billion humans at risk of contracting JEV via the bite of *Culex* mosquitoes, especially *Cx. tritaeniorhynchus* and *Cx. vishnui* which are associated with rice farming in Asia. In addition to the *Culex* spp. mosquitoes characterized as competent JEV vectors, it is noteworthy that JEV has a relatively wide range of susceptible vector species as several natural isolates of JEV were also reported in *Anopheles* and *Aedes* spp. mosquitoes.45
West Nile Virus

Features
- WNV is a member of the flavivirus genus and belongs to the Japanese encephalitis antigenic complex of the family Flaviridae.
- WNV can cause a fatal neurological disease in humans.
- However, approximately 80 per cent of people who are infected will not show any symptoms.
- WNV is mainly transmitted to people through the bites of infected mosquitoes.
- The virus can cause severe disease and death in horses.
- Vaccines are available for use in horses but not yet available for people.
- Birds are the natural hosts of WNV.

Where found:
WNV, another medically important flavivirus in the JEV serocomplex, was first isolated from the blood of a febrile woman in the West Nile district of Uganda in 1937. It is the most widely distributed of the flaviviruses, with strains from one of the two WNV lineages distributed throughout Southeast Asia, southern and Eastern Europe, Australia, and recently, the Americas.46 The largest outbreaks occurred in Greece, Israel, Romania, Russia and the United States. Outbreak sites are on major bird migratory routes. In its original range, WNV was prevalent throughout Africa, parts of Europe, Middle East, West Asia and Australia. Since its introduction in 1999 into the United States, the virus has spread and is now widely established from Canada to Venezuela.

Impact on children:
Most children infected with WNV have only mild, flu-like symptoms that last a few days. Symptoms usually appear within three to 14 days of infection.

Transmission:
WNV is spread by the bite of an infected mosquito. Mosquitoes become infected when they feed on infected birds. Infected mosquitoes can then spread WNV to humans and other animals when they bite. Horses, just like humans, are ‘dead-end’ hosts, meaning that while they become infected, they do not spread the infection. However, the virus may also be transmitted to humans through contact with other infected animals, their blood or other tissues. In a very small number of cases, WNV also has been spread directly from an infected person through blood transfusions, organ transplants, breastfeeding and during pregnancy from mother to baby (transplacental).

Vectors:
WNV is unusual since it has been reported to be infectious to more than 60 species of mosquito vectors.47 WNV is maintained in nature in a mosquito-bird-mosquito transmission cycle. Mosquitoes of the genus Culex are generally considered the principal vectors of WNV, in particular Cx. Pipiens. WNV is maintained in mosquito populations through vertical transmission (adults to eggs).
SPECIES OF MOSQUITOES

AEDES species
Except where otherwise indicated, the information presented was extracted from:

http://entnemdept.ufl.edu/creatures/aquatic/aedes_aegypti.htm
http://entnemdept.ufl.edu/creatures/aquatic/asian_tiger.htm

General information
Adult female Aedes aegypti (L.) are the principal vectors for dengue, urban yellow fever, chikungunya, and Zika viruses, globally important human arboviruses. Ae. albopictus (Skuse) can also act as a secondary vector for DENV along with 22 other arboviruses, some of which have an increasing public health burden. Aedes aegypti is the most competent vector of dengue, yellow fever and Zika viruses. The Asian tiger mosquito is considered a maintenance vector and occasionally is involved with dengue transmission in Asia.

Yellow fever mosquitoes, Aedes aegypti, are day feeding, container-inhabiting mosquitoes; often breeding in unused flowerpots, spare tyres, untreated swimming pools, and drainage ditches. They thrive in urbanized areas, in close contact with people, making them an exceptionally successful vector. Ae. aegypti is extremely common in areas lacking piped water systems, and depends greatly on stored water for breeding sites. Male and female adults feed on the nectar of plants; however, females take blood primarily from humans in order to produce eggs. Eggs have the ability to survive desiccation for long periods of time, allowing eggs to be easily spread to new locations.

The Asian tiger mosquito, Aedes albopictus, is a competent vector of many viruses including dengue fever and Eastern equine encephalitis virus. Its life cycle is closely associated with human habitat, and it breeds in containers with standing water, often tyres or other containers. It is a daytime feeder and can be found in shady areas where it rests in shrubs near the ground. Ae. albopictus feeding peaks in the early morning and late afternoon; it is an opportunistic and aggressive biter with a wide host range, including man, domestic and wild animals.

Ae. albopictus thrives in a wider range of water-filled breeding sites than Ae. aegypti, including coconut husks, cocoa pods, bamboo stumps, tree holes and rock pools, in addition to artificial containers such as vehicle tyres and saucers beneath plant pots. This diversity of habitats explains the abundance of Ae. albopictus in rural as well as peri-urban areas and shady city parks.

Ae. aegypti is more closely associated with human habitation and uses indoor breeding sites, including flower vases, water storage vessels and concrete water tanks in bathrooms, as well as the same artificial outdoor habitats as Ae. albopictus.

**Description**

The adult yellow fever mosquito is a small- to medium-sized mosquito, approximately 4 to 7 millimeters. To the unaided eye, adult yellow fever mosquitoes resemble the *Asian tiger mosquito* with a slight difference in size and thorax patterns. *Ae. aegypti* adults have white scales on the dorsal (top) surface of the thorax that form the shape of a violin or lyre, while adult *Ae. albopictus* have a white stripe down the middle of the top of the thorax. Each tarsal segment of the hind legs possesses white basal bands, forming what appear to be stripes. The abdomen is generally dark brown to black, but also may possess white scales.\(^5\)\(^8\)

**Geographic distribution**

**Figure 1.** The distribution of the occurrence database for *Ae. aegypti* (top) and *Ae. albopictus* (bottom).

Key: The probability of occurrence is from 0 blue to 1 red.

Source: [https://elifesciences.org/content/4/e08347#fig1s4](https://elifesciences.org/content/4/e08347#fig1s4).\(^5\)\(^9\)
Life stages

*Aedes albopictus* overwinter in the egg stage in temperate climates but are active throughout the year in tropical and subtropical habitats.  

Egg

After taking a complete blood meal, females produce on average 100 to 200 eggs per batch; however, the number of eggs produced is dependent on the size of the blood meal. Females can produce up to five batches of eggs during a lifetime. A smaller blood meal produces fewer eggs. Eggs are laid on damp surfaces in areas likely to temporarily flood, such as tree holes and man-made containers, and are laid singly, rather than in a mass. Bowls, cups, fountains, tyres, barrels, vases and any other container storing water make for a great ‘nursery’. It only takes a very small amount of water to attract a female mosquito. Not all the eggs are laid at once, but egg laying can be spread out over hours or days, depending on the availability of suitable substrates. Most often, eggs will be placed at varying distances above the water line, and a female will not lay the entire clutch at a single site, but rather spread out the eggs over two or more sites. Eggs are very hardy; they stick to the walls of a container like glue and can survive drying out, or desiccation, for up to eight months.

Eggs of *Ae. aegypti* are long, smooth, ovoid shaped, and approximately one millimetre long. When first laid, eggs appear white but within minutes turn a shiny black. In warm climates, such as the tropics, eggs may develop in as little as two days, whereas in cooler temperate climates, development can take up to a week.

Larva

Mosquito larvae are often called ‘wrigglers’ or ‘wigglers’, because they appear to wiggle sporadically in the water when disturbed. Larval *Ae. aegypti* breathe oxygen through a posteriorly located siphon, which is held above the water surface while the rest of the body hangs vertically. Most *Aedes* larvae can be distinguished from other genera by the unaided eye by their short siphon.

Larvae feed on organic particulate matter in the water, such as algae and other microscopic organisms. Most of the larval stage of *Ae. aegypti* is spent at the water’s surface, although they will swim to the bottom of the container if disturbed or when feeding.

Larvae are often found around the home in puddles, tyres, or within any object holding water. Larval development is temperature dependent. The larvae pass through four instars (stages), spending a short amount of time in the first three, and up to three days in the fourth instar. Fourth
instar larvae are approximately eight millimeters long. Males develop faster than females, so males generally pupate earlier. If temperatures are cool, *Ae. aegypti* can remain in the larval stage for months so long as the water supply is sufficient.68

**Figure 4. Fourth instar larva of the yellow fever mosquito, *Aedes aegypti* (Linnaeus)**

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**Figure 5. Larvae of *Aedes* and *Culex* showing typical vertical hanging behaviour**


**Pupa**

After the fourth instar, *Ae. aegypti* enter the pupal stage. Mosquito pupae are different from many other holometabolous insects in that the pupae are mobile and respond to stimuli. Pupae, also called ‘tumblers’, do not feed and take approximately two days to develop. Adults emerge by ingesting air to expand the abdomen thus splitting open the pupal case and emerge head first.

**Figure 6. Pupa of the yellow fever mosquito, *Aedes aegypti* (Linnaeus)**

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**Adapt**

*Ae. aegypti* is a holometabolous insect, meaning that it goes through a complete metamorphosis with an egg, larva, pupa and adult stage. The adult life span can range from two weeks to a month depending on environmental conditions.69 *Ae. aegypti* comes in three polytypic forms: domestic, sylvan and peridomestic. The domestic form breeds in urban habitats, often around or inside houses. The sylvan form is a more rural form, and breeds in tree holes, generally in forests, and the peridomestic form thrives in environmentally modified areas such as coconut groves and farms.70

**Lifespan and flight range**

The adult lifespan of the *Ae. aegypti* mosquito can range from two weeks to a month depending on temperature and other environmental conditions.71 The average *Ae. aegypti* mosquito will disperse relatively short distances (<100m) but females have been shown to travel at least 800 metres in six days.72

**Population dynamics**

*Ae. aegypti* adults peaked in February, May–June, and again in September, during a study in Parque des Dunas de Natal (Brazil). During the same study, increasing numbers of eggs were found during February and again in July with larval densities peaking one month later.73

Previous
studies have shown populations of *Ae. aegypti* to remain active in Egypt throughout winter, in Spain from the summer through to December, in Morocco in October and December and in Algeria up to the end of the summer and early winter.\(^{74}\)

*Ae. albopictus* tropical and subtropical populations are active throughout the year with no overwintering.\(^{75}\) Temperate populations are affected by seasonal temperature and photoperiodicity and, in response to these factors, can overwinter by producing eggs that undergo a winter diapause (resting stage).\(^{76}\) The species’ ability to induce photoperiodic egg diapause allows it to overwinter in temperate regions, which assists its establishment in more northern latitudes in Asia, North America and Europe. Diapausing eggs of European *Ae. albopictus* have been shown to be able to survive a cold spell of -10°C, whereas eggs of tropical *Ae. albopictus* could only survive -2°C. Some populations in North America are likely to be exposed to mean temperatures of -5°C and will overwinter if females have deposited eggs in containers that are not exposed to these temperatures for prolonged periods — e.g., artificial containers in peridomestic areas.\(^{77}\) *Aedes albopictus* populations in Italy are showing signs of cold acclimation as adults and are thus remaining active throughout winter.\(^{78}\)

### Patterns of feeding and resting

The domestic form of *Ae. aegypti* is often found no further than 100 metres from human habitats\(^{79}\) although some studies have shown that breeding habitats can also be found further away from human dwellings.\(^{80}\) *Ae. aegypti* prefer human habitations as they provide resting and host-seeking possibilities\(^{81}\) and as a result will readily enter buildings.\(^{82}\), \(^{83}\) Their activity is both diurnal and crepuscular.\(^{84}\), \(^{85}\)

*Ae. albopictus* is an opportunistic feeder.\(^{86}\) Blood hosts include humans, domestic and wild animals, reptiles, birds and amphibians.\(^{87}\) Laboratory studies and blood meal analysis have shown a preference for human blood meals.\(^{88}\) A recent study in Italy found a preference for mammals as opposed to birds, and found human blood meals were more frequent in urban areas than rural sites, suggesting that host availability and abundance has a direct impact on the feeding activities of *Ae. Albopictus*.\(^{89}\)

### Vector status

**Aedes aegypti**


*Aedes aegypti* is known to transmit DENV, YFV, chikungunya virus and Zika virus. It is suggested to be a potential vector of Venezuelan equine encephalitis virus\(^{91}\) and vector competency studies have shown *Ae. aegypti* is capable of transmitting WNV. WNV has also been isolated from this mosquito species in the field.\(^{92}\)

As human population growth occurs in the future, sites in which this mosquito thrives will increase, providing further habitats for establishment. This coupled with the close proximity of humans to one another, and the tendency of *Ae. aegypti* to feed on multiple hosts during one gonotrophic cycle,\(^{93}\), \(^{94}\) increases the risk of disease transmission in such areas. The movement of viraemic hosts can result in outbreaks from a number of arboviruses in non-endemic areas. It is estimated that 22.5 million people travel to Europe each year and 185,000 of these could be viraemic for chikungunya alone.\(^{95}\)

Unlike *Ae. albopictus*, the ability for *Ae. aegypti* to establish in more temperate regions is currently restricted due to its intolerance to temperate winters\(^{96}\) but it could become widely established again in the Mediterranean and this could change in the future with global climate change, resulting in the northern and southern expansion of *Ae. aegypti*.\(^{97}\)
**Aedes albopictus**


During the 2006-2007 period, the vector status of *Ae. albopictus* changed when chikungunya virus was reported in Italy and *Ae. albopictus* mosquitoes were responsible for its transmission.99 This mosquito is also known to transmit dengue virus100,101 and Dirofilaria.102,103 All four dengue virus serotypes have been isolated from *Ae. albopictus*.104

*Ae. albopictus* is considered to be a competent vector experimentally of at least 22 other arboviruses including YFV, Rift Valley fever virus, JEV, WNV and Sindbis virus, all of which are relevant to Europe because they can be transported by humans from other regions. Zika virus, Potosi virus, Cache Valley virus, La Crosse virus, Eastern equine encephalitis virus, Mayaro virus, Ross River virus, Western equine encephalitis virus, Venezuelan equine encephalitis virus, Oropouche virus, Jamestown Canyon virus, San Angelo virus and Trivittatus virus are other arboviruses that *Ae. albopictus* can transmit experimentally.105,106,107

A number of these viruses have also been isolated from field-collected *Ae. albopictus* in different countries and laboratory transmission of such viruses by *Ae. albopictus* has been demonstrated.108 These include Eastern equine encephalitis virus,109 La Crosse virus,111,112 Venezuelan equine encephalitis virus,113,114 WNV115,116,117 and JEV.118 Usutu virus has been isolated from *Ae. albopictus* in Italy, but it is unknown whether the mosquito can transmit this pathogen.119 Field isolation and experimental infection studies alone do not prove that this mosquito species is involved in the transmission of such viruses, but the mosquito’s biting habits, increasing global distribution and recent involvement in a chikungunya virus outbreak highlight the significance of *Ae. albopictus* to public health.

A high prevalence of the insect-infective Aedes flavivirus has been detected in *Ae. albopictus* in Italy and it has been suggested that its presence in these mosquitoes could influence the transmission dynamics of other human-pathogenic flaviviruses, such as WNV and the Usutu virus.120

Not only does *Ae. albopictus* represent a disease risk but it can also cause a considerable amount of nuisance biting in areas where it is well-established, reducing the quality of life of individuals affected.121 Prevalence of *Ae. albopictus* has also been linked to a reduction in children’s outdoor physical activity time, a factor contributing to childhood obesity.122

For information on other *Aedes* species, see ECDC 2014.123

- *Aedes atropalpus* – West Nile Fever, Japanese encephalitis
- *Aedes koreicus* – Japanese encephalitis

**ANOPHELES species**

Except where otherwise noted, all information is from [https://www.cdc.gov/malaria/about/biology/mosquitoes](https://www.cdc.gov/malaria/about/biology/mosquitoes).124

**General information**

There are approximately 3,500 species of mosquitoes grouped into 41 genera (*Anopheles, Aedes, and Culex* among others). Human malaria is transmitted only by females of the genus *Anopheles*. Of the approximately 430 *Anopheles* species, only 30 to 40 transmit malaria (i.e., are vectors) in nature. The most
aggressive transmitters of disease are found in the *Anopheles gambiae* complex found mostly in Africa (recognized as a species complex only in the 1960s). The *A. gambiae* complex consisted of seven species:125

- *Anopheles arabiensis*
- *Anopheles bwambae*
- *Anopheles melas*
- *Anopheles merus*
- *Anopheles quadriannulatus*
- *Anopheles gambiae* sensu stricto

**Geographic distribution**

Anophelines are found on all continents except Antarctica. Malaria is transmitted by different *Anopheles* species, depending on the region and the environment. Thus, areas where the malaria parasite transmission has been eliminated, but the mosquito is still present, are at constant risk of re-introduction of the disease.

**Life stages**

Like all mosquitoes, anophelines go through four stages in their life cycle: egg, larva, pupa and adult. The first three stages are aquatic and last five to 14 days, depending on the species and the ambient temperature. The adult stage is when the female *Anopheles* mosquito acts as a malaria vector. The adult females can live up to a month (or more in captivity) but most probably do not live more than one to two weeks in nature.

Each species of *Anopheles* mosquito has its own preferred aquatic habitat; for example, some prefer small, shallow collections of fresh water, such as puddles and animal hoof prints, which are abundant during the rainy season in tropical countries.

**Eggs**

Adult females lay 50-200 eggs per oviposition. Eggs are laid singly directly on water and are unique in having floats on either side. Eggs are not resistant to drying and hatch within two or three days, although hatching may take up to two

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**Figure 7. Distribution of a range of *Anopheles* spp. vectors**


Centers for Disease Control and Prevention
to three weeks in colder climates. The female Anopheles mosquito will lay her eggs in a wide range of locations. Malaria mosquito breeding grounds can be fresh water or salt water, vegetative or non-vegetative, shady or sunlit. Ground pools, small streams, irrigated lands, freshwater marshes, forest pools and any other place with clean, slow-moving water are all considered prime malaria mosquito breeding grounds for egg-laying.

Larva
Mosquito larvae have a well-developed head with mouth brushes used for feeding, a large thorax and a segmented abdomen. They have no legs. In contrast with other mosquitoes, Anopheles larvae lack a respiratory siphon and for this reason position themselves so that their body is parallel to the surface of the water. Larvae breathe through spiracles located on the eighth abdominal segment and therefore must come to the surface frequently.

The larvae spend most of their time feeding on algae, bacteria and other microorganisms in the surface microlayer. They dive below the surface only when disturbed. Larvae swim either by jerky movements of the entire body or through propulsion with the mouth brushes.

Larvae develop through four instars, after which they metamorphose into pupae. At the end of each instar, the larvae molt, shedding their exoskeleton, or skin, to allow for further growth.

The larvae occur in a wide range of habitats but most species prefer clean, unpolluted water. Larvae of Anopheles mosquitoes have been found in fresh and salt-water marshes, mangrove swamps, rice fields, grassy ditches, the edges of streams and rivers, and small, temporary rain pools. Many species prefer habitats with vegetation. Others prefer habitats that have none. Some breed in open, sunlit pools while others are found only in shaded breeding sites in forests. A few species breed in tree holes or the leaf axils of some plants.

Pupa
The pupa is comma-shaped when viewed from the side. The head and thorax are merged into a cephalothorax with the abdomen curving around underneath. As with the larvae, pupae must come to the surface frequently to breathe, which they do through a pair of respiratory trumpets on the cephalothorax. After a few days as a pupa, the dorsal surface of the cephalothorax splits and the adult mosquito emerges.

The duration from egg to adult varies considerably among species and is strongly influenced by ambient temperature. Mosquitoes can develop from egg to adult in as little as five days but usually take 10-14 days in tropical conditions.

Adult
Like all mosquitoes, adult anophelines have slender bodies with three sections: head, thorax and abdomen.

Anopheles mosquitoes can be distinguished from other mosquitoes by the palps, which are as long as the proboscis, and by the presence of discrete blocks of black and white scales on the wings. Adult Anopheles can also be identified by their typical resting position: males and females rest with their abdomens sticking up in the air rather than parallel to the surface on which they are resting.
Adult mosquitoes usually mate within a few days after emerging from the pupal stage. In most species, the males form large swarms, usually around dusk, and the females fly into the swarms to mate.

Males live for about a week, feeding on nectar and other sources of sugar. Females will also feed on sugar sources for energy but usually require a blood meal for the development of eggs. After obtaining a full blood meal, the female will rest for a few days while the blood is digested and eggs are developed. This process depends on the temperature but usually takes two to three days in tropical conditions. Once the eggs are fully developed, the female lays them and resumes host seeking.

**Lifespan**

As noted above, anophelines go through four stages in their life cycle: egg, larva, pupa and adult. The first three stages are aquatic and last 5-14 days, depending on the species and the ambient temperature. The adult females can live up to a month (or more in captivity) but most probably do not live more than one to two weeks in nature.

It is not possible to measure directly the life span of mosquitoes in nature. But indirect estimates of daily survivorship have been made for several Anopheles species. Estimates of daily survivorship of An. gambiae in Tanzania ranged from 0.77 to 0.84, meaning that at the end of one day between 77 per cent and 84 per cent will have survived.\(^{126}\)

**Patterns of feeding and resting**

Most *Anopheles* mosquitoes are crepuscular (active at dusk or dawn) or nocturnal (active at night). Some *Anopheles* mosquitoes feed indoors (endophagic) while others feed outdoors (exophagic). After blood feeding, some *Anopheles* mosquitoes prefer to rest indoors (endophilic) while others prefer to rest outdoors (exophilic).

**CULEX species**

Information on the *Culex* species is from R. Subra (1981).\(^{128}\)
General information

_Culex_ is a diverse genus having several species of the _Culex_ complex that can transmit zoonotic diseases affecting humans and wild and domestic animals, such as lymphatic filariasis, Rift Valley Fever, avian malaria, St. Louis encephalitis, Western equine encephalitis, and West Nile fever, and may be a vector of the Zika virus. Females cause infection while biting when obtaining a blood meal. In India and Southeast Asia, _Culex_ is the primary vector of _Wuchereria bancrofti_, a nematode that causes lymphatic filariasis.

Table 5. _Culex_ vectors and diseases spread in regions

**ASIA PACIFIC**
- JEV
- Filarial worms
- Murray Valley encephalitis
- Ross River viruses

**NORTH AMERICA**
- WNV
- St. Louis encephalitis virus
- Western equine encephalitis
- Dog heartworm

**AFRICA**
- WNV
- Filarial worms

**EUROPE, MIDDLE EAST**
- WNV
- Filarial worms

**CENTRAL AND S. AMERICA**
- Venezuelan equine encephalitis virus
- Filarial worms
The spread of *Culex* species has been aided by natural human population increases and subsequent growth in size of towns compounded by the large migratory movement of people to the cities, which has led to the overcrowding of numerous quarters. The disposal of the various types of waste has been left by authorities in part to the inhabitants themselves, who have often dug poorly constructed, insanitary latrines or soakage pits. Thus, sanitation services in most cases have been unable to deal adequately with this influx of people. The southern house mosquito, *Culex quinquefasciatus*, has therefore been able to easily colonize all those breeding places. They are among the most common mosquitoes found in urban settings.

### Description

Considered to be a medium-sized mosquito, the adult house mosquito, *Culex pipiens*, may reach up quarter of an inch. The species’ body is usually brownish or grayish brown. The proboscis and wings are usually brown.

In the field informal identification is more often important, and the first question as a rule is whether the mosquito is anopheline (*Anopheles*) or culicine (*Culex* or *Aedes*). Anopheline mosquitoes tend to have dappled or spotted wings, while Culicine wings tend to be clear. Anopheline mosquitoes tend to sit with their heads low and their rear ends raised high, especially when feeding, while Culicine females keep their bodies horizontal. The length of the maxillary palps (mouthparts) should be noted. Palps as long as the proboscis are characteristic of anopheline mosquitoes. Culicine females have short palps.iv

### Geographic distribution

**Figure 9.** *Culex* species are found across the globe with exception of the extreme northern latitudes

![Map of Culex species distribution](https://www.researchgate.net/figure/259386615_fig1_Figure-1-Global-distribution-of-Cx-pipiens-complex-mosquitoes-Geographic-range-for-Cx)

Source: [https://www.researchgate.net/figure/259386615_fig1_Figure-1-Global-distribution-of-Cx-pipiens-complex-mosquitoes-Geographic-range-for-Cx](https://www.researchgate.net/figure/259386615_fig1_Figure-1-Global-distribution-of-Cx-pipiens-complex-mosquitoes-Geographic-range-for-Cx)

**Life stages**

The developmental cycle of most species takes about two weeks in warm weather. Mature *C. quinquefasciatus* females fly at night to nutrient-rich standing water to lay eggs. The larvae feed on organic material in the water and require between five and eight days to complete their development at 30°C. The larvae pass through four larval instars, and towards the end of the fourth instar, they stop eating and undergo molting to give rise to pupae. After 36 hours at 27°C, adults emerge. The exact timing of development can vary depending on temperature. Both males and females take sugar meals from plants. But after mating, the female seeks a blood meal on mammals and birds. Ingested blood is necessary for egg development. A single female can lay up to five rafts of eggs in a lifetime, with each raft containing about 300 eggs. The exact number varies depending on climatic conditions.

**Egg**

*C. p. quinquefasciatus* eggs are laid in the form of rafts which can float on the surface of the water. An average of 155 eggs per raft. In tropical countries, hatching usually occurs one day after egg-laying.

**Larva**

The two main factors that regulate mosquito larval growth are nutrition and the temperature of the water in the breeding places. Though waste water represents the main breeding sources, the larvae can develop in virtually any type of breeding place found in the human environment. Most breeding sites are of medium size (a few cubic meters) or small (a few litres), and the species can develop in either sunny or shady places.

**Pupa**

Pupae are known as tumblers because of the way they seem to tumble through the water. Their rounded, comma-like shape makes this mode of movement easy. These pupae do not eat during the one or two days in which they become an adult mosquito.

The larval stage lasted between six and eight days and pupal stage about 40 hours. The wide range of the incubation and larval periods that have been observed may be due to temperature differences of the larval breeding places in various types of soakage pits: a difference of several degrees was observed between surface water at ground level and that deep down in the pits. *C. p. quinquefasciatus* develops mainly in habitats containing highly polluted water rich in organic matter that the larvae can use for nourishment.
is complete, the pupal skin splits and the adult mosquito (imago) emerges.

**Figure 12. Culex pupae or tumbler**

![Culex pupae or tumbler](medent.usyd.edu.au)

**Adult**

**Figure 13. Culex adult taking blood meal**

![Culex adult taking blood meal](Dept. Medical Entomology, ICPMR)

### Breeding sites

#### Highly polluted water

Latrines are the most widespread type of breeding place in most countries. The water mixed with excreta therefore constitutes a highly polluted environment perfectly suited to *C. quinquefasciatus* larvae. Furthermore, since latrines are usually protected against heavy rainfall, which may flood other breeding places, their production of larvae during the rainy season continues practically uninterrupted.

Soakage pits are designed to collect waste washing and cooking water. These consist of holes dug in the ground to varying depths, sometimes filled with pebbles. Most are accessible from the outside, as the covered top is rarely completely sealed or mosquito proofed. Heavy rain may cause the pits to overflow, providing less stable breeding places than latrines. Unlike latrines, however, they contain water throughout most of the year and represent actual or potential breeding places over a longer period. In quarters where housing is modern and of good quality, septic tanks form the main breeding places. They maintain high culicid densities almost uninterruptedly throughout the year.

Key sewage system *Culex* include:

- *Culex pipiens*
- *Culex quinquefasciatus*

Ditches and gutters designed to drain rain water in towns frequently become breeding places for *C. p. quinquefasciatus* if not properly cleaned. The organic detritus that accumulates pollutes the water often to a high degree, and furthermore prevents normal flow, thus providing excellent conditions for larval development.

Key drainage system *Culex* mosquitoes include:

- *Culex pipiens*
- *Culex quinquefasciatus*
- *Culex molestus*
- *Culex restuans*

Various used containers thrown away through negligence (or lack of sanitary education of the inhabitants) are excellent breeding sites. They may be the remains of jars, empty tins, bottles, broken metal cans, broken coconut husks, bamboo stalks and shells. These containers fill with water in the rainy season and act as mosquito breeding places during that time of the year. In towns, old tyres, which often accumulate in large numbers, constitute important breeding places for both *Ae. aegypti* and *C. quinquefasciatus*. 
**Figure 14.** Typical tyre pile that serves as container breeding site for *Culex* and *Aedes* mosquitoes

![Image of a tyre pile](Valent BioSciences)

Key container *Culex* include:
- *Culex pipiens*
- *Culex quinquefasciatus*

**Clean water**

In the absence of polluted water for breeding, *C. p. quinquefasciatus* can utilize sites containing limpid water used for domestic needs of the population including existing wells for drinking or irrigation, and tanks and cisterns.

Small receptacles or containers represent a widespread type of breeding place in all tropical areas of the world. In regions where the inhabitants still pursue a traditional way of life, water for domestic use is stored mainly in earthenware jars which may hold up to several dozen litres. In more modern environments, these easily breakable jars are often replaced by metal containers with a capacity of as much as 200 litres. When the water is changed irregularly, or at too great intervals (several weeks), mosquito larvae can develop. *C. p. quinquefasciatus* and *Aedes aegypti* can be found in such containers.

**Natural larval habitats**

Natural sites are usually small and *C. p. quinquefasciatus* is often found breeding with other species. By themselves, they doubtless contribute quite small adult numbers; but they cannot be disregarded in campaigns designed to interrupt disease transmission. Three categories of breeding place have been observed which differ greatly from each other in origin and structure: tree-holes, crab burrows and coral rock holes.

Common open habitat *Culex* mosquitoes include:
- *Culex pipiens*
- *Culex quinquefasciatus*
- *Culex tarsalis*
- *Culex nigripalpus*
- *Culex salinarius*
- *Culex modestus*
- *Culex annulirostris*
- *Culex sitiens*

An examination of the various types of *C. p. quinquefasciatus* breeding places in the Ethiopian faunal region as a whole shows two differences: the types of larval habitats in urban and rural areas are not always identical, and the particular types of important breeding place vary in degree of infestation in different regions of the continent.

**Patterns of feeding and resting**

Anthropophilic mosquitoes feeding at night and bite man either inside dwellings (endophagy) or outside (exophagy). It may happen that certain individuals of the same species facultatively feed indoors and others outdoors. Furthermore, this behaviour may differ from one region to another.

The large majority of female *C. p. quinquefasciatus* feed at night. When they bite man it is mainly below the knee if the person is sitting, or on any part of the body if they are lying down. Similar observations have been made by other authors studying the biting cycle of endophagous females. Most biting specimens were collected after midnight in the Comoro Islands\textsuperscript{132} and in East Africa.\textsuperscript{133}
In Rangoon (Burma), Lindquist et al., estimated the flight range of *C. p. quinquefasciatus* at 1 kilometre. In the same city, Subra (1981) later made a more or less identical estimate, mosquitoes flying a greater distance being the exception. In fact, most specimens fly less than 500 to 600 metres from the point of release. In uninhabited areas, on the other hand, mosquitoes are able to fly for several kilometres. Thus, it seems that in its classical environment, an inhabited region, *C. p. quinquefasciatus* rarely flies more than a few hundred metres. However, this distance does not represent potentialities inherent in the species which, in an uninhabited area, can travel much further.

In the same way, some specimens choose resting places inside dwellings, while others find shelter outdoors. The tendency of mosquitoes to stay inside dwellings is called endophily, and the opposite tendency exophily, although it should be made clear that during the gonotrophic cycle the same female may exhibit both tendencies.

On the basis of the above data, it is possible to sketch an outline of the behaviour of *C. p. quinquefasciatus* adults during the different phases of the gonotrophic cycle. The mosquito generally spends only a few hours in the vicinity of the breeding place from which it emerged. It then makes one or more flights, which take it to another shelter either inside a house or outdoors. When they reach the appropriate age, the females take their first blood meal, mostly inside dwellings where they then pass the first few hours after the blood meal. Most of them then leave the dwellings and digestion is completed outdoors in some shelter. Exophagic females, once they have taken a blood meal, undergo their gonotrophic cycles in the outdoor shelters already mentioned. Some may even enter inhabited houses after biting man or animals outside. In any case the females, whether endophilic or exophilic, carry out a series of movements by day and night, throughout their gonotrophic cycle.

### Population dynamics

In Upper Volta, peak female densities in urban areas have been recorded in the rainy season and at the beginning of the dry season. In north-east Tanzania, in a suburban locality, *C. p. quinquefasciatus* densities had two peaks corresponding to the two rainy seasons, the peak densities occurring during the lesser rainy season. There is a marked relationship between rainfall and the peak breeding periods. A single peak corresponds to a single rainy season (West Africa and the Comoro Islands), while two peaks correspond to the two rainy seasons (East Africa). The differences between maximum and minimum densities are generally great. Thus, in West Africa, mean densities in the rainy season are often 10 times as high as in the dry season. Similarly, in the Comoro Islands, Brunhes found an almost complete absence of the species during the dry season in Grand Comoro and in some villages in Mayotte. This was not, however, a general phenomenon, since in other villages, according to the same author, the reduction observed was only by a half between the two seasons; this difference is doubtless due to the nature of the breeding places and sites of the villages studied.

### Lifespan

*Culex tarsalis*, a common California (USA) mosquito, might go through its life cycle in 14 days at 21.1°C and take only 10 days at 26.6°C. On the other hand, some species have naturally adapted to go through their entire life cycle in as little as four days or as long as one month.
Determining the best interventions

The efficacy of any control programme depends on the target mosquito vector, local settings, intervention type, resources and sustainability. Entomological surveillance is the key to any successful vector control programme. It provides early warning to mobilize medical and control resources that can contain a disease before outbreak occurs. Local involvement in vector control activities, for example search and eliminate for breeding sites or ‘Hang Up and Keep Up’ net distribution campaigns, increases the likelihood that community-oriented interventions will impact vector indices and lead to a reduction of outbreaks for many vector borne diseases. Mathematical models indicate that spatially or temporally targeting existing vector control interventions may be more effective than applying them evenly across different locations and times. Likewise, targeting control on mosquito life stages other than adults (larvae and pupae) may be more effective than previously thought based on the Ross-Macdonald theory.

Although the concept of integrated intervention for disease prevention is gaining increasingly broader acceptance, to date, consensus is still to be reached regarding the details of how and what combination of approaches can be most effectively implemented to manage disease. For example, malaria is prevented with effective tools (nets and residual spraying) but those tools are under continuous threat of insecticide resistance in the vector populations. Today, there is a widespread perception that *Aedes aegypti* control has ‘failed’ or that existing methods will not reduce viral transmission (dengue, chikungunya, Zika, yellow fever), and that this is why existing approaches should be abandoned and there should be no effort to invest in or pursue alternative strategies. As recent reviews and meta-analyses show, this is incorrect.

It is not surprising that 80 per cent of the studies included in this review were published in the past seven years. This reflects the increase in attention and resources devoted to finding effective control strategies that contain the growing importance of this vector and the potential for a disease pandemic.

Best practices in vector control must be defined for each setting (i.e., which tools or methods the community should employ), as well as what constitutes adequate or sufficient coverage in order to impact the vector population and virus transmission. This includes governmental commitment, operational aspects, quality of delivery and best combination of interventions for successful vector control during outbreaks. The combinations of interventions will differ between routine programmes (Table A) and outbreaks that require immediate reactive measures (Table 6). Different responses will also have different outcomes depending whether applied in an urban or rural setting or a refugee crisis situation.
Table 6. Interventions for mosquito control in outbreak situations

<table>
<thead>
<tr>
<th>Mosquito</th>
<th>Urban</th>
<th>Rural</th>
<th>Refugee / Crisis</th>
<th>Rationale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anopheles</td>
<td>Indoor Residual Spraying</td>
<td>Bednets (LLIN)</td>
<td>Indoor Residual Spraying</td>
<td>Biting most frequently inside during night; resting on walls; spraying immediately reduces density, nets provide personal protection</td>
</tr>
<tr>
<td>Bed nets (long-lasting insecticidal nets)</td>
<td>Bed nets (long-lasting insecticidal nets)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aedes Culex</td>
<td>Larvicide</td>
<td>Larvicide</td>
<td>Larvicide</td>
<td>Day biting outdoors; container breeding; larvicide provides immediate reduction of density; adults rest where not easy to spray; Culex resistant to pyrethroids</td>
</tr>
<tr>
<td>Source reduction</td>
<td>Source reduction</td>
<td>Source reduction</td>
<td>Protective clothing</td>
<td></td>
</tr>
<tr>
<td>Protective clothing</td>
<td>Protective clothing</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

There is a vital need for robust, rigorously designed field trials with epidemiological and entomological outcomes to improve the understanding of how well existing tools can reduce vector borne disease transmission and their optimal implementation. Only then can strategy-specific programmes be realistically developed and evaluated.146

Biting by nocturnal, endophagric Anopheles mosquitoes can be markedly reduced through the use of insecticide-treated bed nets (ITNs) or through improved housing construction to prevent mosquito entry (e.g., window screens). Endophilic mosquitoes are readily controlled by indoor spraying of residual insecticides. In contrast, exophilic/exophagous vectors are best controlled through source reduction (destruction of the breeding sites).

A multicentre study in Asia for Aedes control was conducted between 2006 and 2011 in urban and peri-urban areas of six countries. Where it was considered an eco-biosocial approach, it generated evidence relevant to the adoption of controls based on the principles of Integrated Vector Management (IVM). The results suggest that for a more sustainable control there should be involvement of several partners, including the local community. The interventions should be directed at a significant reduction of infestation in breeding areas. New non-insecticidal tools should be adopted such as lids or container covers and introducing predators of the vector.146

Additionally, while limited evidence demonstrates some reduction in vector indices following outdoor fogging, evidence is still needed to show an impact on disease incidence.147

Despite adversities encountered in the various analyses, the consensus is that integrated intervention provides the most effective method for the control of Ae. aegypti. This strategy succeeds because multidisciplinary and multisectoral involvement not only eliminates the vectors but also because the social and environmental shortcomings that contribute to vector proliferation are corrected. Community participation improved all interventions employed associated with it and so it is an indispensable component in any control programme.148

Limitations:
Horstick et al., (2015) found that: (1) vector control could be effective, but implementation and coverage remained an issue; (2) single interventions were probably not useful; (3) combinations
of interventions had mixed results; (4) careful implementation of vector control measures may be most important; and (5) outbreak interventions were often applied with questionable effectiveness. Although the concept of vector control is reasonable, control must be early in an outbreak or strategically applied during inter-epidemic periods to prevent escalation in transmission. At the local level, emergency legislation for immediate access to vacant lots, households, schools, and/or offices may be required to allow comprehensive attention to key virus transmission sites.

However, the primary reason for the inability to recommend a specific existing intervention for either sustained management or epidemic mitigation is the paucity of data providing clear evidence of a direct, positive health impact, i.e., reduced human vector borne disease cases. The trends are clear from reductions in entomological indices that a number of technologies have been validated, but more large-scale, randomized trials are needed to establish disease impact.

**Adult control methods**

**Outdoor**

**Space spray / fogging**

Space spraying, using different insecticides, is one of the most commonly used vector control methods.

**Table 7. Selected insecticides suitable for cold or thermal fogging for mosquito control**

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Dosage of active ingredient (g/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organophosphates</td>
<td>Varies by active ingredient</td>
</tr>
<tr>
<td>fenitrothion</td>
<td>250–300</td>
</tr>
<tr>
<td>malathion</td>
<td>112-600</td>
</tr>
<tr>
<td>pirimiphos-methyl</td>
<td>250</td>
</tr>
<tr>
<td>pyrethroids</td>
<td>Varies by active ingredient</td>
</tr>
<tr>
<td>cyfluthrin</td>
<td>1-6</td>
</tr>
<tr>
<td>deltamethrin</td>
<td>0.5-1.0</td>
</tr>
<tr>
<td>lambda-cyhalothrin</td>
<td>1.0</td>
</tr>
<tr>
<td>permethrin</td>
<td>5-10</td>
</tr>
<tr>
<td>resmethrin</td>
<td>2-4</td>
</tr>
</tbody>
</table>

The systematic review of space spraying by Esu et al., (2010) included 15 studies of which 13 showed reductions in immature entomological indices that were not sustained for long periods. The remainder showed space spray interventions to be ineffective at reducing adult and/or immature entomological indices. Only one study measured human disease indicators, but its outcomes could not be directly attributed to space sprays alone. Although peridomestic space spraying is commonly applied by national dengue control programmes, there are very few studies evaluating the effectiveness of this intervention and there is no clear evidence for recommending peridomestic space spraying as a single effective control intervention. Bowman et al., (2016) reported there was insufficient evidence from randomized controlled trials to determine whether or not insecticide space-spraying or fogging could impact dengue transmission.
interventions (aerial and truck mounted ultra-low volume space-spraying) were not recommended in WHO guidelines due to lack of impact on mosquito population reduction and lack of cost-effectiveness for routine delivery.\textsuperscript{156}

**Indoor**

**Indoor Residual Spraying**

IRS is the application of a long-lasting, residual insecticide to potential mosquito vector resting surfaces such as internal walls, eaves and ceilings of all houses or structures (including domestic animal shelters) where such vectors might come into contact with the insecticide.\textsuperscript{156} The timing of IRS applications, or ‘rounds’, is a critical factor for a successful programme. Best practice is to schedule the completion of spray application to coincide with the build-up of vector populations just before the onset of the peak transmission season. This ensures fresh deposits of insecticides during periods of peak mosquito density. It is usually not operationally feasible to conduct more than two rounds of IRS in one year; ideally, areas that can be protected with a single round of IRS per year are chosen. With timely, good-quality spraying, most recommended insecticides (particularly pyrethroids, a new organophosphate formulation, and DDT) are effective for six months or longer.

Insecticides recommended by WHO for IRS fall into four major classes:

- carbamates (C): bendiocarb, propoxur
- organochlorines (OC): DDT
- organophosphates (OP): malathion, fenitrothion, pirimiphos-methyl
- pyrethroids (PY): alphacypermethrin, deltamethrin, lambda-cyhalothrin, etofenprox, bifenthrin, cyfluthrin

**Table 8. WHO-recommended insecticides for IRS against malaria vectors**

<table>
<thead>
<tr>
<th>Insecticide compounds &amp; formulations\textsuperscript{1}</th>
<th>Class group\textsuperscript{2}</th>
<th>Dosage (g a.i./m\textsuperscript{2})</th>
<th>Mode of action</th>
<th>Duration of effective action (months)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DDT WP</td>
<td>OC</td>
<td>1-2</td>
<td>Contact</td>
<td>&gt;6</td>
</tr>
<tr>
<td>Malathion WP</td>
<td>OP</td>
<td>2</td>
<td>Contact</td>
<td>2-3</td>
</tr>
<tr>
<td>Fenitrothion WP</td>
<td>OP</td>
<td>2</td>
<td>Contact &amp; airborne</td>
<td>3-6</td>
</tr>
<tr>
<td>Pirimiphos-methyl WP, EC</td>
<td>OP</td>
<td>1-2</td>
<td>Contact &amp; airborne</td>
<td>2-3</td>
</tr>
<tr>
<td>Pirimiphos-methyl CS</td>
<td>OP</td>
<td>1</td>
<td>Contact &amp; airborne</td>
<td>4-6</td>
</tr>
<tr>
<td>Bendiocarb WP, WP-SB</td>
<td>C</td>
<td>0.1-0.4</td>
<td>Contact &amp; airborne</td>
<td>2-6</td>
</tr>
<tr>
<td>Propoxur WP</td>
<td>C</td>
<td>1-2</td>
<td>Contact &amp; airborne</td>
<td>3-6</td>
</tr>
<tr>
<td>Alpha-cypermethrin WP, SC</td>
<td>PY</td>
<td>0.02-0.03</td>
<td>Contact</td>
<td>4-6</td>
</tr>
<tr>
<td>Alpha-cypermethrin WG-SB</td>
<td>PY</td>
<td>0.02-0.03</td>
<td>Contact</td>
<td>Up to 4</td>
</tr>
<tr>
<td>Bifenthrin WP</td>
<td>PY</td>
<td>0.025-0.05</td>
<td>Contact</td>
<td>3-6</td>
</tr>
<tr>
<td>Cyfluthrin WP</td>
<td>PY</td>
<td>0.02-0.05</td>
<td>Contact</td>
<td>3-6</td>
</tr>
<tr>
<td>Deltamethrin WP, WG, WG-SB</td>
<td>PY</td>
<td>0.02-0.025</td>
<td>Contact</td>
<td>3-6</td>
</tr>
<tr>
<td>Deltamethrin SC-PE</td>
<td>PY</td>
<td>0.02-0.025</td>
<td>Contact</td>
<td>6</td>
</tr>
<tr>
<td>Etofenprox WP</td>
<td>PY</td>
<td>0.1-0.3</td>
<td>Contact</td>
<td>3-6</td>
</tr>
<tr>
<td>Lambda-cyhalothrin WP, CS</td>
<td>PY</td>
<td>0.02-0.03</td>
<td>Contact</td>
<td>3-6</td>
</tr>
</tbody>
</table>

\textsuperscript{1} CS, capsule suspension; EC, emulsifiable concentrate; SC, suspension concentrate; SC-PE, polymer-enhanced suspension concentrate; WG, water-dispersible granule; WG-SB, water-dispersible granules packaged in water-soluble bags; WP, wettable powder; WP-SB = wettable powder in sealed water soluble bags.

\textsuperscript{2} OC, organochlorines; OP, organophosphates; C, Carbamates; PY, pyrethroids.

**Note:** WHO recommendations on the use of pesticides in public health are valid only if linked to WHO specifications for their quality control. WHO specifications for public pesticides are available on the WHO website at [http://www.who.int/whopes/quality/en/](http://www.who.int/whopes/quality/en/)
The WHO (2015) provides a complete review of considerations for IRS products with the publication of *Indoor Residual Spraying: an Operational Manual for indoor residual spraying (IRS) for malaria transmission control and elimination – 2nd ed.*\(^{157}\) Topics include formulations, sprayable surfaces, spray equipment, registration, environmental risks, packaging, storage, safety precautions/handling and resistance management. The manual also outlines the complications of conducting an IRS campaign.

Pluess et al., (2010) reviewed 134 studies where IRS, either alone or compared with ITNs or long-lasting insecticidal nets (LLIN), was the primary *Anopheles* control intervention for a Cochrane meta-analysis of IRS.\(^{158}\) They concluded historical and programme documentation has clearly established the impact of IRS. However, there were too few high-quality trials to quantify the size of effect in different transmission settings. The evidence from randomized comparisons of IRS versus no IRS confirmed that IRS reduces malaria incidence in unstable malaria settings, but randomized trial data from stable malaria settings is very limited. Some limited data suggested that ITN give better protection than IRS in unstable areas, but more trials were needed to compare the effects of ITNs with IRS, as well as to quantify their combined effects.

IRS is not generally recommended for *Aedes* vector control, as it is thought that adult *Ae. aegypti* often rest on non-sprayable surfaces in houses such as hanging clothing.\(^{159}\) However, dramatic reductions in *Ae. Aegypti* populations were observed in places where IRS was routinely used for malaria control.\(^{160}\)

### Long-Lasting Insecticidal Nets

LLINs are nets that are factory-treated to bind or incorporate insecticide into or onto a net’s fibres. They are designed to maintain their biological efficacy against vector mosquitoes for at least 20 washes (ideally three years) under recommended conditions of use in the field, obviating the need for regular insecticide re-treatment. As Anophelines are night biters, malaria transmission can be effectively prevented by sleeping under a LLIN. According to models and estimates by Bhatt et al., (2015) it is estimated that of the 663 million clinical malaria cases averted since 2000, 68 per cent of these were averted by ITNs as the most widespread intervention.\(^{161}\)

In 2007, WHO released the *Manual for Malaria Program Managers: Long-lasting insecticidal Nets for Malaria Prevention.*\(^{162}\) It was designed as a practical guide on malaria prevention through the use of ITNs. The manual covers topics such as the evidence base for routine usage; impact on child mortality and morbidity; impact on diseases other than malaria; delivery strategies; communication strategies, monitoring and evaluation; resource requirements and implementation research.

All mosquito nets work by acting as a physical barrier to vector mosquitoes, thus affording personal protection against malaria to the individuals sleeping directly...
under nets. The pyrethroid insecticides used to treat nets to have an excito-repellent effect that adds a chemical barrier to the physical one. This increases the protective efficacy of the mosquito net by further reducing human-vector contact. The insecticide kills mosquitoes that come into contact with the ITN or LLIN. Thus, by reducing the vector population, ITNs and LLINs provide protection for everyone in the community, even people who do not sleep under a net themselves. In this case ITNs and LLINs work as vector control interventions in reducing malaria transmission. A recent study has shown that relatively modest coverage (30–60 per cent, depending on the ecological scenario) of all adults and children can achieve equitable, community-wide benefits. However, it is noted that mosquito resistance to pyrethroids is increasing and will affect the future use of this technology.

Since 2009, UNICEF has procured and helped to distribute nearly 188 million mosquito nets in over 30 countries. Most nets are distributed through integrated maternal and child health services, but UNICEF also contributes significant logistical and operational support to countries around efforts to achieve high mosquito net coverage and significant reductions in malaria illness and deaths. UNICEF’s LLIN procurement in 2015 totaled 22.3 million nets, slightly less than the 26.5 million in 2014. However, UNICEF projected demand for 2016 to increase to reach approximately 40 million LLINs. The supply landscape remains stable and the estimated aggregate production capacity is now significantly higher than market demand. Globally, LLIN deliveries reached approximately 207 million during 2015, all focused on malaria prevention (AMP Net Delivery Data, August 2016). v

The behaviour of Aedes mosquito differs markedly from the malaria carrying Anopheles mosquito as it bites primarily during daylight hours, especially just before dusk and as the day dawns. With the exception of adults or children napping during the day where a net might provide some protection, LLINs are not a practical prevention technology for viruses spread by Aedes vectors.

Culex spp. exhibited considerable tolerance to pyrethroids, the only class of chemistry used on nets. LLINs may provide limited protection against Culex vectors of lymphatic filariasis. However, the disease is vectored by a number of mosquito species, such as Anopheles, so LLIN would not be a core defense technology.

**Lethal ovitraps**

A lethal ovitrap is a device which attracts gravid female container-breeding mosquitoes and kills them. The traps halt the insect’s life cycle by killing adult insects and stopping reproduction. Lethal ovitraps can either contain substances that kills larvae that hatch from eggs laid in the traps (larvicidal ovitraps), or substances that kill the adult mosquito when she enters, along with any larva that may hatch (adulticidal ovitraps). Lethal ovitraps have been used in field studies to show their effectiveness in reducing mosquito populations below disease-transmission thresholds.

Early attempts in Brazil and Thailand demonstrated reduction in Ae. aegypti adult and larval populations, but did not meet expectations required for elimination. Quinbayo et al., (2014) observed that the ovitraps with deltamethrin were the most efficient, showing the best results. In field conditions, the ovitraps with the highest vector reduction were those combining deltamethrin/towel/10 per cent hay infusion.

When referencing lethal ovitraps, the WHO states, “Studies have shown that population densities can be reduced with sufficiently large numbers of frequently serviced traps. Life expectancy of the vector may also potentially be shortened, thus reducing the number of vectors that become infective” (See [http://www.who.int/denguecontrol/research/en/](http://www.who.int/denguecontrol/research/en/)).

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v See [http://www.vector-works.org/resources/itn-access-and-use/](http://www.vector-works.org/resources/itn-access-and-use/).
Spatial repellents
Spatial repellents are products designed to release volatile chemicals into the air and prevent human-vector contact within the treated space. Deployment of spatial repellent products in enclosed and semi-enclosed spaces will reduce pathogen transmission. Spatial repellents may be particularly amenable to swift deployment with high public health impact.

In Australian houses, metofluthrin has been shown to rapidly reduce biting and, in some cases, kill adult Ae. aegypti without expelling them through open windows. Field studies in Viet Nam have shown densities of adult Ae. aegypti inside homes treated with metofluthrin plastic latticework strips to be significantly lower than those in untreated houses for six weeks. Randomized, cluster-controlled trials (cRCT) using mosquito coils containing either transfluthrin or metofluthrin in China and Indonesia, respectively, have demonstrated protective efficacy against new malaria infections with an associated reduction in vector densities and biting rates at sentinel homes, respectively.

Personal repellents
The most common active ingredients are useful to prevent attacks from day-biting mosquitoes such as Aedes and Culex. Personal protection by use of repellents is not a long-term solution for vector borne disease prevention.

There are several types of insect repellents for application on the skin with different chemical ingredients, concentrations, formulations and forms of delivery. These factors determine product efficacy and safety against various insects for different populations. There are no clear guidelines on the selection of specific products in the context of long-term protection of populations in affected areas and general recommendations are based on general advice for a variety of settings and products available in specific markets.

Insecticide-treated materials
These materials (curtains, jar lids, and window screening) provide novel ways to reduce mosquito populations by mechanically blocking adults from laying eggs (jar lids) or entering houses (screens). The insecticide treatment on curtains kills adults that land, thereby reducing population density below transmission thresholds.

Curtains
In a cRCT in Mexico, ITMs – specifically insecticide-treated curtains (ITCs) – were found to impact on vector populations. In a cRCT trial in Venezuela, ITMs consisting of curtains and water jar-covers (made from PermaNet) were distributed under routine field conditions in 10 clusters (five urban and five suburban), with over 4,000 houses, in Trujillo (Venezuela). At distribution, the proportion of households with ≥1 ITC curtain was 79.7 per cent in urban and 75.2 per cent in suburban clusters, but decreased to 32.3 per cent and 39.0 per cent, respectively, after 18 months. The corresponding figures for the proportion of jars using ITM covers were 34.0 per cent and 50.8 per cent at distribution and 17.0 per cent and 21.0 per cent after 18 months, respectively. The authors concluded deployment of ITCs in households can result in significant reductions in A. aegypti levels when dengue vector infestations are moderate, but the magnitude of the effect depends on the coverage attained, which itself can decline rapidly over time.

Early tests of ITCs to reduce mosquito populations in Guatemala were encouraging. This was not the case in Thailand, where the open character of local housing cancelled out any impact. Differences in results may have been due to
differences in the structure of houses at the two study locations. A randomized trial in Colombia also reported impacts on the vector population by long-lasting insecticide-treated netting used as window and door curtains, both alone or in combination with insecticide-treated netting water container covers.\textsuperscript{178}

**Screening**

A trial in Mexico using permanently mounted, insecticide-treated netting screens fitted to the doors and windows of residential houses, followed in a second year by additional larviciding with Spinosad, demonstrated a rapid and sustained impact on the vector population for over 12 months.\textsuperscript{179, 180}

In a systematic review of evidence for improved housing, Tusting et al., (2015) screened 15,526 studies, of which 90 were included in a qualitative synthesis and 53 reported epidemiological outcomes, included in a meta-analysis.\textsuperscript{181} They stated that housing improvements, traditionally a key pillar of public health, remain underexploited in malaria control. In sub-Saharan Africa, where 80-100 per cent of malaria transmission occurs indoors at night, the home can be a place of high risk. Screening homes was shown to reduce malaria risk in India, South Africa and the United States. More recent studies indicate that well-built, modern housing can be protective in many tropical countries. Simple features, including closed eaves (the gap between the top of the wall and the over-hanging roof), brick walls, tiled or metal roofs, or ceilings can reduce mosquito house entry. In a randomized-controlled trial in The Gambia, untreated door and window screens and closed eaves halved the prevalence of anaemia in children.

Vazquez-Prokopec et al., (2016) noted that scalable housing improvement interventions must be engineered to be durable and cost-effective.\textsuperscript{182} In the case of screenings, there is need for innovation in the development of screen material that is both durable and can retain insecticidal effect over the long term. Simple ways to firmly attach screening material to door and window frames that are highly variable in size, shape and construction material could lead to reductions in intervention costs and facilitate installation.

Bowman et al., (2016) also reported that house screens on external doors and windows could be protective against dengue transmission.\textsuperscript{183} Of those that could be assessed adequately, the method with the most evidence supporting its effectiveness in preventing dengue transmission was house screening. Data from cross-sectional\textsuperscript{184} and case control studies\textsuperscript{185} in Australia, and a case control study in Taiwan\textsuperscript{186} were included in a meta-analysis that indicated a significant protective effect of window and door screens on dengue transmission as detected by serology (ELISA\textsuperscript{vi} or haemagglutination inhibition assay). Although the weaker study designs limited the power of this result, the results are encouraging. *Aedes aegypti* exhibit predominantly indoor resting and

\textsuperscript{vi.} Enzyme-linked immunosorbent assay.
blood feeding behaviour (termed endophagic and endophilic behaviour, respectively)\textsuperscript{187} and barriers to access would be expected to impact on this species. Malaria vector mosquitoes and other arthropods of medical importance are also active indoors and can be targeted in the same way, increasing the likelihood of perception of benefit and adoption by householders. Mosquito-proofing houses was first considered over a century ago, and its potential as a sustainable and effective tool for malaria control has been evaluated in randomized controlled trials in recent years.\textsuperscript{188},\textsuperscript{189},\textsuperscript{190} New investigations of screening for dengue prevention are also underway.

Recent studies in a high-risk dengue setting in Mexico reported that window and door screens were a popular and widely adopted intervention that significantly reduced domestic infestations of \emph{Aedes aegypti}\textsuperscript{191},\textsuperscript{192} House screening is not included in the current WHO dengue guidelines, but given its potential and wide ranging benefits, it is a strong candidate for randomized controlled trials to evaluate its effectiveness in preventing dengue.\textsuperscript{193}

\textbf{Jar lids}

Socheat et al., (2004) evaluated 19 versions of locally produced jar lids in Cambodia.\textsuperscript{194} Based on the assessment, one jar cover in particular stood out from the other designs as appearing to be the most suitable. It comprised of a simple rattan hoop, with a slightly larger circumference than the rim of the jar, and supporting a fine mesh net. A stone attached to a string was hung from the centre, anchoring the lid so that it would not blow off in strong winds. Attaching the stone also proved to be useful when taking water from the jar, as the lid could be moved aside and the stone prevented it from falling off, thus making it easier to reposition.

The researchers also learned locally appropriate solutions such as jar covers can be designed or adapted to keep mosquitoes from water containers, and substantial improvements can be made during the design and trial phases if participatory research is used to actively engage intended end-users. Participatory field trials yield important information on the attitudes of villagers and their requirements for jar covers. They may also contribute to the development of new solutions.

Quintero et al., (2015) installed curtains in 922 households and water container covers in 303 households.\textsuperscript{195} The Breteau index (percentage of houses with pupae) per fell from 14 to 6 in the intervention group and from eight to five in the control group. The additional intervention with LLIN covers for water containers showed a significant reduction in the pupae per person index ($p<0.01$). In the intervention group, the pupae per person index showed a clear decline of 71 per cent compared with 25 per cent in the control group. The majority of containers that produced >78 per cent of pupae were containers >200 L; after the intervention with LLIN covers the pupae productivity decreased from 970 to 388 (60 per cent) and in the control group from 394 to 339 (16 per cent). The other container types were responsible for 12 per cent pupal production, especially small buckets. After using them, 60.1 per cent (182/303) of residents reported a willingness to pay for the covers, 83.2 per cent (252/303) said they would recommend them to friends and neighbors, and 89.8 per cent (272/303) said they would be happy to receive them again if they were free.

As with other vector control technologies, the impacts of ITMs on dengue transmission have not yet been reported.\textsuperscript{196}

\textbf{Larval control methods}

Larviciding is a general term for killing immature mosquitoes by applying agents, collectively called larvicides, to control mosquito larvae and pupae. Most organized mosquito control programmes use larvicide as a management practice because it both minimizes the area in which control procedures must be applied and reduces the need for adult control. At these times, larviciding has a high impact on local population
numbers (especially those in the genera of *Aedes* and *Culex*) with minimal application effort. It is critical to have a thorough knowledge of the biology of the targeted species in order to determine the appropriate larvicide, the timing of the application, and the amount of product to be applied. It is important to select the appropriate control agent and formulation based on performance and other factors. There are a variety of products and formulations within each larvicide classification. Specific formulations are different from manufacturer to manufacturer. Application rates and suggested treatment sites may differ as well. Individual product labels, usually downloadable from manufacturers’ websites, should be consulted for specific information, habitat dependent application rates, and restrictions, if any. 197

Recent quantitative assessments indicate that under certain circumstances larval control may result in larger than previously expected reductions in pathogen transmission. 198

Mosquito larvicides fall within the following classification system:

**Insect growth regulators**

- **Methoprene**: A juvenile hormone analog which acts as a growth regulator. It does not kill insects. Instead, it mimics natural juvenile hormones which must be absent for a pupa to molt to an adult. So, methoprene-treated larvae are unable to successfully change from pupae to adults. This breaks the biological life cycle of the insect, preventing recurring infestation.

- **Pyriproxyfen**: A juvenile hormone analog in a different class of chemistry from methoprene. It prevents larvae / pupae from developing into adulthood, thus rendering them unable to reproduce.

Larviciding using the insect growth regulator pyriproxyfen delivered as part of a community-based strategy, was reported to have significantly reduced the rate of dengue incidence in the intervention group: RR 0.19. 199

- **Diflubenzuron**: A stomach and contact insect growth regulator which acts by inhibiting the production of chitin (a compound that makes the outer covering of the insect hard) and so interferes with the formation of the insect’s cuticle or shell (exoskeleton).

- **Novaluron**: Another insect growth regulator in the same class as diflubenzuron. The compound inhibits chitin formation, preventing larvae from reaching adulthood.

**Microbial based larvicides (biologicals)**

- **Bacillus thuringiensis israelensis (Bti)**: A naturally occurring bacterium. Several strains have been commercialized. The active ingredients in Bti formulations are delta-endotoxin (d-endotoxin) crystals separated from bacteria near the end of manufacturing processes. These toxic crystals are incorporated into various products which allow their release into water so that they may be ingested by mosquito larvae. The crystalline d-endotoxins are not activated in the acidic gut of humans or other animals. This specificity accounts for the highly selective nature of Bti larvicides which is limited to Dipterans, notably mosquitoes, black flies and some midges. Bti controls all larval instars provided they are still feeding. It is effective on most mosquito species in a very wide variety of habitats; Bti formulations are thus ideally suited for Integrated Pest Management (IPM).
Systematic reviews of 14 reports were reviewed by Boyce et al., (2013). They found 12 reported reductions in entomological indices with an average duration of control of two to four weeks. Bti can be effective in reducing the number of immature Aedes in treated containers but there is very limited evidence – one study – that dengue morbidity can be reduced through the use of Bti alone. Hence, there is currently insufficient evidence to recommend its use as a single agent for the long-term control of dengue vectors.

- **Bacillus sphaericus (Bs):** A naturally occurring spore-forming bacterium that acts in a manner similar to Bti, except it has been shown to maintain some residual activity. The spores can invade the body cavity of the larvae where they have the capability to germinate, grow and produce toxins. This process is known as recycling.

  The activity of Bs d-endotoxins differs from that of Bti in several important ways. Bs toxins are attached to a living bacterial spore while the Bti toxins are not. The toxins of Bs and Bti bind to chemically different receptor cell sites. They are not related immunologically and are thought to have completely different molecular modes of action.

- **Spinosad:** An insecticide based on chemical compounds found in the bacterial species *Saccharopolyspora spinosa*. It is a mixture of two chemicals called spinosyn A and spinosyn D. The spinosyns have a novel mode of action, primarily targeting binding sites on nicotinic acetylcholine receptors of the insect nervous system that are distinct from those at which other insecticides have their activity. Spinosyn binding leads to disruption of acetylcholine neurotransmission.

**Organophosphates**

These work after entry into and distribution through the body of a target organism by modifying the normal functions of some nerve cells by inhibiting the activity of cholinesterase enzymes at the neuromuscular junction. This action results in the accumulation of acetylcholine, thereby interfering with neuromuscular transmission. In insects, organophosphates produce a loss of coordination leading to paralysis and ultimately death.

- **Temephos:** One of the few larvicides approved by WHO for treatment of drinking water (granular formulation).

The systematic literature review by George et al., (2015) assessed the community effectiveness of the organophosphate temephos (or Abate®) in controlling both vectors and dengue transmission when delivered either as a single intervention or in combination with other interventions. A total of 27 studies were included, comprising 11 single and 16 combined intervention studies. All single intervention studies showed consistently that temephos applications reduced entomological indices and 11 of the 16 combined intervention studies showed that temephos application together with other chemical vector control methods also reduced entomological indices. The community-effectiveness of temephos was found to be dependent on factors such as quality of delivery, water turnover rate, type of water and environmental factors such as organic debris, temperature and exposure to sunlight. Timing of temephos deployment and its need for reapplication, along with behavioural factors such as the reluctance of its application to
drinking water, and operational aspects such as cost, supplies, time and labour were further limitations identified in this review.

- **Fenthion**: Like most other organophosphates, its mode of action is via cholinesterase inhibition. Amid concerns of harmful effects on environment, especially birds, The Environmental Protection Agency of the United States has classified fenthion as a Restricted Use Pesticide, and warrants special handling because of its toxicity.

- **Pirimiphos-methyl**: An organophosphate that has demonstrated effectiveness against *Culex* mosquitoes in highly polluted water.

  Fenthion and pirimiphos-methyl were found to be highly effective larvicides against *Cx. quinquefasciatus* larvae in sewers.\(^{202}\)

**Surface oils and films**

- **Surface oils also** are considered one of the most effective tools for pupal control and can control newly emerged adults that are resting on the water surface when drying their wings. It is usually a mineral oil having additives incorporated to improve its physical performance. Larviciding oils are non-selective, and mosquito control efficacy is limited to those species which breathe air at the water surface. An oil slick can be viewed on the water surface. Both their odour and appearance may be objectionable, precluding widespread use in some areas.

- **Monomolecular films**: Biodegradable, ethoxylated alcohol surfactants, made from renewable plant oils, monomolecular film are lighter than water and do not mix particularly well with it. As their name implies, monomolecular films are self-spreading and produce an extremely thin film on the water's surface. They act by significantly reducing the surface tension of the water and wetting mosquito structures, which leads to drowning of larvae, pupae and emerging adults.

  Wang et al., (2013) showed that the monomolecular film called Aquatain AMF was very effective at controlling the *Aedes* pupal stage (100 per cent mortality), but had limited efficacy against small larvae (38 per cent mortality) and large larvae (78 per cent mortality).\(^{203}\) The larvicidal oil was effective against all immature stages (93.3-100 per cent mortality). They concluded that for effectively interrupting the dengue transmission cycle, larvicides that kill the pupal stage (Aquatain AMF or larvicidal oil) should be included in an emergency dengue control programme in addition to *Bti*, pyriproxyfen or temephos.

**Biological larval control**

This is the introduction of natural enemies of mosquitoes into aquatic habitats, e.g., predatory fish, invertebrates, parasites or other organisms.

- **Larvivorous fish**

  Han et al., (2015) reviewed the evidence for the effectiveness of larvivorous fish for *Aedes* control and dengue prevention.\(^{204}\) The 13 articles identified incorporated a wide range of interventions and outcome measures, with three efficacy studies, 10 of which assessed community effectiveness. All efficacy studies reported that *Aedes* larvae were eliminated from treated containers. Community effectiveness studies reported reductions in immature vector stages, two of which also detected a continuous decline over two years. An impact on adult mosquitoes was shown in two community effectiveness studies. While the use of larvivorous fish as a single agent or in combination with other control measures could lead to reductions in immature vector stages, considerable limitations in all the studies restricted any conclusions with respect to the evaluation of community effectiveness.

  Certain fish species can reduce the density of mosquito larvae by predation in aquatic habitats; however, a systematic review of studies using larvivorous fish showed no convincing evidence that they suppress *Anopheles* larval populations enough to reduce malaria in the local human population.\(^{205}\)
• **Predatory copepods**
  A systematic review of the use of copepods (microscopic predatory crustaceans) identified 11 articles, focusing on efficacy and community effectiveness.\(^{206}\) There was evidence from Viet Nam that *Mesocyclops spp.* had the potential to impact on vector populations in the long term, contributing to reductions in dengue cases. However, this success has not yet been replicated elsewhere (six studies). With this limited evidence for the use of copepods as a single intervention, further implementation studies in other communities/environments are needed.

The main disadvantages of biological predators are associated with the intense work to maintain the organisms in the containers that depend on favourable environmental factors, in addition to the emptying of reservoirs, and the escape or death of the organisms.\(^{207}\) It should be emphasized that communities are usually against using fish in their drinking containers.\(^{208}\)

**Sterile insect techniques**

The sterile insect technique is a method of biological insect control, whereby overwhelming numbers of sterile insects are released into the wild. The sterile males compete with wild males to mate with the females. Females that mate with a sterile male produce no offspring, thus reducing the next generation’s population. Sterile insects are not self-replicating and, therefore, cannot become established in the environment.

• **OX513A RIDL (Release of Insects with Dominant Lethality)** from Oxitec technology (Oxford, UK). *Ae. Aegypti* has two genetically modified genes inserted and the modified population is reared on antibiotic media that prevents expression of the lethal gene. Once released, the modified males mate with wild females and the gene is lethal to pupae.\(^{209}\) It has been tested successfully in Brazil\(^{210}\) and Oxitec has a factory in Piracicaba producing 60 million males per week, enough to protect 3 million people. This will be validated in a large-scale trial in 2017. The Cayman Islands Mosquito Research and Control Unit (MRCU) has government approval for expanded testing in the Cayman Islands for 2017.\(^{211}\) Oxitec is waiting for EUP from the Environmental Protection Agency and the Food and Drug Administration of the United States to conduct trial in the Florida Keys.

• **Wolbachia bacteria**

  MosquitoMate® technology (Lexington, Kentucky, USA). Bacteria lives intracellularly in insects, is maternally inherited, and passes through to eggs. The bacteria is genetically modified in males so it is incompatible with that of wild females and prevents fertilization. Professor Scott O’Neill of Monash University in Australia believes the bacteria interferes with virus development in the mosquito and thus disease transmission.\(^{212}\) His team is developing a system that relies on auto-dissemination by males (ADAM).

• **Irradiation**

  o In Austria, the Food and Agriculture Organization has been irradiating many insect pest species for years using x-rays. They need a bio property to separate the sexes so only non-biting males will be released. It is believed wolbachia bacteria can be used to separate the sexes.

  o The idea is to combine irradiation with bacteria using local genetic bloodlines. The outcome would be no transmitting females, no antibiotics and no resistance.

  o The concept has not been tested yet.

Novel control technologies mentioned in this review still require validation of efficacy (against mosquitoes, disease impact and understanding of limitations. For example, the *Ae. Aegypti* sterile insect control strategies will have time-lagged impacts on adult populations. Those kinds of interventions will be best applied in sustained, proactive implementation and will likely be inadequate for rapid control of a developing epidemic.\(^{213}\)
### Table 9. Novel vector control technologies requiring performance validation

<table>
<thead>
<tr>
<th>Development intervention</th>
<th>Best circumstances</th>
<th>Challenges if already in use</th>
<th>Challenges in new contexts</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wolbachia (transmission blocking or population reduction)</strong></td>
<td>Dense urban environment; feasible introduction threshold; spatially homogeneous mosquito density; <em>Ae. aegypti</em> exclusive vector</td>
<td>Roll-out in megacities; large-scale production of mosquitoes; stackable adult traps and deployment from back of vehicle; cheap, easy diagnostic for Wolbachia infection</td>
<td>Organization + consumer product market</td>
</tr>
<tr>
<td><strong>Lethal ovitraps</strong></td>
<td>Small area; few alternative containers for egg-laying &amp; larval development; a dry season; island, other isolated area; no larvicide resistance</td>
<td>Local production; delivery system</td>
<td>Consumer acceptance; willingness to pay</td>
</tr>
<tr>
<td><strong>RIDL, fsRIDL</strong></td>
<td>Dense urban environment; seasonal mosquito density; stable, consistent funding &amp; commitment; island, other isolated area</td>
<td>Community acceptance; regulatory approvals; infrastructure to support rearing and routine releases</td>
<td>Organization; improved rearing procedures; better operational support to dynamically identify where to deploy mosquitoes; automated release using GPS</td>
</tr>
<tr>
<td><strong>Auto-dissemination</strong></td>
<td>Small area; few alternative containers for egg-laying &amp; larval development; a dry season; island, other isolated area; no larvicide resistance</td>
<td>Active ingredient</td>
<td>-</td>
</tr>
<tr>
<td><strong>Behavioural manipulation (to include spatial repellents)</strong></td>
<td>Enclosed housing structure; strictly indoor biting; no diversion</td>
<td>User acceptability; willingness to pay</td>
<td>Create a consumer-driven product and strategy; Evidence of impact; combination of top down and bottom up delivery and distribution channels; market surveys for greater end user uptake of products</td>
</tr>
</tbody>
</table>
Larval source management

A distinction will be drawn between operations aimed at eliminating breeding sites on a relatively permanent basis (environmental modification), and those which tend only to get rid of unstable and generally small breeding places temporarily (environmental manipulation). Waste water can be discharged either through well-designed soakage pits in which mosquito larvae can no longer develop, or by building sewers which at the same time avoid accumulation of stagnant rainwater and replace latrines. Disappearance of breeding places of this type would considerably reduce the densities of *C. p. quinquefasciatus* and would lead to large savings in both insecticides and manpower. However, the development of such systems requires large investments often beyond the available resources of a particular state.

It is nevertheless the aim to which all concerned should be directing their efforts, even if it is not immediately attainable.

Besides the breeding places mentioned above, which are characterized by their stability and large size, there are small collections of water resulting from human activity or negligence (tins, broken bottles, etc.). Their elimination by the health services or the inhabitants themselves can also help to reduce adult densities. The most important problem here is to convince populations of the need to continue their efforts and thus to avoid a return to the status quo once the first enthusiasm has died down. Here health education must play a primary role, since there can be no permanent environmental improvement without the cooperation of the local population. This situation has led many authorities responsible for vector control to believe that the control of *C. p. quinquefasciatus* is ineffective or at least requires means that are out of reach of their financial resources. Integrated control aims primarily at combining methods, which if applied separately, would not achieve the desired result but together are mutually complementary.214

According to the WHO ‘Toolkit for Integrated Vector Management’ larval source management includes any of the following:

- **Habitat modification:** A permanent alteration to the environment, aimed at eliminating larval habitats. Includes landscaping, drainage of surface water, land reclamation and filling, covering large water storage containers (for example, wells) with mosquito-proof lids and permanent slabs, building covered areas to store potential breeding sites (for example, shelters for tyres) or completely covering water surfaces with a material that is impenetrable to mosquitoes (for example, expanded polystyrene beads).

- **Habitat manipulation:** Temporary environmental changes to disrupt vector breeding. Includes water level manipulation, flushing of streams, drain clearance, shading, proper disposal of garbage, regular emptying and cleaning of domestic containers (e.g., flower pots, animal drinking-water troughs) and exposing habitats to the sun, depending on vector ecology.

- **Removal of dangerous man-made aquatic habitats and safe waste disposal.**215
Probably the most widespread practices to suppress dengue vector populations are clean-up campaigns, typically community-driven and in tandem with education and health promotional campaigns as well as numerous additional approaches such as IRS and larviciding. Identification of, and targeted action towards, ‘productive’ container types (i.e., those that are assessed as contributing the greatest burden of pupae, relative to other containers in the area) can potentially enable more cost-effective larval control. Results from a cRCT in Nicaragua and Mexico reported reductions in dengue sero-conversion rates and self-reported dengue cases as well as vector indices, following community mobilization to deliver pesticide-free vector control. Reductions in potential larval development sites can be achieved with householders and communities taking responsibility, supported by education and social mobilization.

A systematic review and meta-analysis found that multiple CBIs (such as environmental management or clean up campaigns, refuse collection, the formation of community working groups, social mobilization strategies, water covers, and larviciding) can significantly reduce vector densities. Results from a cRCT in Latin America reported reductions in dengue cases following similar interventions.

An assessment of waste management as a single intervention in a cRCT in Sri Lanka reported a reduction in pupal indices. A cRCT in India established the effectiveness of a combination of water container covers and clean-up campaigns, including community mobilization. In a cRCT in Brazil, a combination of a clean-up campaign, the use of container covers, and community mobilization failed to have a substantial effect.

Comprehensive container larvicide treatment (with insecticides or biologicals) and container removal are recommended for sustained management of immatures, and thus, indirectly, adult Aedes, based on demonstration of small-scale successes using combinations of interventions. Social mobilization campaigns (education, public relations), environmental management and legislation (enforcement and incentives) were considered effective as components of sustained mitigation programmes. Failure of dengue vector control strategies has often been associated with the absence of active local community involvement.
Communities can be mobilized to take responsibility for and implement vector control actions if participatory community-based approaches are in place to facilitate their active engagement in vector control. The aim is to ensure that healthy behaviours with vector control outcomes become part of the social fabric and that communities take ownership of vector control interventions.

Efforts to engage communities could act in concert with regulatory or legislative actions to support some preventive interventions, for example property access for larvicide application. Governments and disease control programmes should advocate for including community engagement strategies in the policy agenda and budget which may require explaining current and emerging threats, the need for uptake of new tools and interventions and the importance of dialogue to promote ownership of vector control interventions by communities.

**Biological control** was found to achieve higher reduction of mosquito populations than chemical control. Chemical control, which is commonly used, does not appear to be associated with sustainable reductions of mosquito populations over time. Indeed, by contributing to a false sense of security, chemical control may reduce the effectiveness of educational interventions aimed at encouraging local people to remove mosquito breeding sites.

For their review vector control strategies were categorized as: (1) chemical controls (including insecticide and larvicide applications), (2) biological controls (where a biological agent was used), (3) educational campaigns (focused on training and awareness of the general public with the aim of reduction/elimination of breeding sites) and (4) integrated vector controls (comprising two or more individual control strategies, i.e., IVM).

Requests

**Bouzid et al., (2016)** published the latest meta-analysis on *Aedes* control in December 2016 by conducting a systematic review of previous systematic reviews on the subject. Starting with 165 articles published from 2011 to 2016 the analysis includes 13 previous systematic reviews that investigated the effect of control measures on entomological parameters or disease incidence. They found the efficacy of any control programme is dependent on local settings, intervention type, resources and study duration, which may partly explain the varying degree of success between studies. In other words, the effectiveness of any control strategy is setting-dependent. Educational campaigns are essential to reduce breeding sites and interrupt disease transmission.

**Integrated vector control strategies** were assessed in nine of the systematic reviews.
Their review suggests that WHO is correct to reiterate that the most effective intervention to control disease and protect populations is the elimination of mosquito breeding sites, which would require sustained and ongoing education campaigns, resource allocation and good governance. This is particularly important considering the resilience of *Aedes aegypti* mosquitoes, with population numbers recovering and increasing shortly after vector control strategies have ceased. Although prevention of mosquito borne diseases has always focused on control of the mosquito vector, there is a debate about whether a rethink of control strategies is warranted. This is relevant considering the day biting pattern and low flight range (<100 m) of *Aedes* mosquitoes. These traits mean that vector control strategies should be focused not only on the peridomestic environment but also on day gathering places such as markets, schools, hospitals etc. and combined with better diagnosis and monitoring/ restriction of the movement of viremic persons, which has been found to be an important driver of dengue spatiotemporal clustering and disease spread.

The systematic reviews that Bouzid et al., assessed suggest that biological control achieves better and more sustainable reduction of entomological indices than chemical control. Chemical control measures could be associated with a false sense of security leading to lesser community engagement with the reduction or elimination of breeding sites. Educational campaigns and community engagement appear paramount in reducing breeding habitats in the peridomestic environment, although ongoing resources must be allocated to ensure educational interventions are maintained.

Separately, Das et al., (2014) reviewed 3,452 reports on CBI for dengue preventive measures significantly reduced dengue positive serostatus by 70 per cent while community education alone did not have a significant impact. However, preventive community-based education plus cleanliness campaigns reduced ovitrap index by 25 per cent. Insecticide spraying and aerosols significantly reduced the house index by 10 per cent. Preventive strategies utilizing guppies in water tanks and the growth of Chinese cat fish to consume larvae also had a significant impact on reducing the house index. Bed nets and curtains had a nonsignificant impact however the studies reported both spillover effects and non-suitable controls. The conclusion was the majority of the studies showed that community delivered interventions have the potential to achieve wider coverage and sustained community acceptance with the approach of combining interventions having a more rapid and sustainable effect than individual interventions. They recommended that a major component of CBI should always be the community itself, as the success of existing neglected tropical disease programmes depends on community structures, customs, beliefs and values.

Al-Muhandis and Hunter (2011) investigated the value of educational messages embedded in a community-based approach to control of *Aedes* vectors for dengue. There were 491 original papers for assessment and 22 separate studies were included in this review. The aim of the review was to investigate different educational messages on the incidence of *Aedes aegypti* larvae using entomological measures such as
relative effectiveness. Relative effectiveness is the ratio between the entomological index in the intervention group and in the control group. The more effective the intervention the lower the relative effectiveness. A relative effectiveness of 1.0 would indicate no effect.

The primary objective was to establish which, if any, of these interventions was most effective in reducing larval indices. Entomological effectiveness was measured using one or more of three widely utilized indices: the Breteau index, container index and house index. The Breteau index specifies the number of containers with Aedes spp. larvae per 100 houses, the container index represents the percentage of water containers positive for Aedes spp. larvae, and the house index gives the percentage of houses with water containers holding immature Aedes spp. In addition, one study used the average number of positive containers per house.

The review systematically analysed only publications which included an educational element to their interventions (even if other non-educational interventions were also included). A rather broad definition of educational intervention included any CBI that had any element where members of the public were given information or exhortations intended to change their behaviour.

The highest effectiveness was seen somewhere around 18 months after the educational intervention. This is consistent with the suggestion that people may need time to learn, but after that their effort and good intentions may slip without reinforcement.

With regard to comparison of educational interventions against one another, results showed that no single intervention modality (such as the use of print or broadcast media, lectures, training by public health staff, home visits or targeting school children) nor the number of different modalities used together was found to improve the relative effectiveness significantly. However, few if any studies were designed to compare different educational intervention modalities and so it could be argued that this issue remains unanswered.

Horstick et al., (2010) undertook an analysis of vector services with two methods: a systematic literature review and case studies that included stakeholder interviews and completion of questionnaires in Brazil, Guatemala, the Philippines and Viet Nam. In the systematic literature review, staffing levels, capacity-building, management and organization, funding and community engagement were found to be insufficient. The case studies confirmed most of these findings, with stakeholders reporting: (1) lack of personnel (entomologists, social scientists and operational vector control staff); (2) lack of technical expertise at decentralized levels of services; (3) insufficient budgets; (4) inadequate geographical coverage; (5) interventions that rely mostly on insecticides; (6) difficulties engaging communities; (7) little capacity-building; and (8) minimal monitoring and evaluation. Stakeholders’ doubts about service effectiveness were widespread, but interventions were assumed to be potentially effective with increased resources. The authors highlighted the need for operational standards; evidence-based selection/delivery of combinations of interventions; development/application of monitoring and evaluation tools; and needs driven capacity-building.

Nicaragua and Mexico

Andersson et al., (2015) conducted a study called Camino Verde, the Green Way, in Nicaragua and Mexico, based upon previous work in Nicaragua evaluating community mobilization for Aedes control. Residents were selected from a random sample of census enumeration areas across both countries. The study including 85,182 residents in 18,838 households. They followed a community mobilization protocol that began with community discussion of baseline results. All clusters continued the government run dengue control programme (monthly deposits of temephos sachets in water storage of all households and space spraying). But, each site implemented the intervention (chemical free prevention of
mosquito reproduction) in its own way that yielded the advantage of local customization and strong community engagement (Table 10).

The results showed informed community mobilization adds effectiveness to government-run dengue control. The Camino Verde project reduced *Ae. aegypti* larvae and pupae and protected against dengue virus infection. It is believed this is the first trial that used serological evidence of recent childhood infection and self-reported dengue cases to show an impact of community mobilization on infection with dengue virus.

They concluded, however, not to expect community participation in dengue control to be easy or easily sustainable. The intervention protocol that engages leadership and community members in discussing evidence and defining local strategies is a promising starting point for a wide range of settings. Each site implementing the intervention in its own way has the advantage of local customization and strong community engagement.

**Table 10. Common interventions for a community-oriented approach in Nicaragua and Mexico**

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Detail</th>
</tr>
</thead>
</table>
| **Evidence** | • Educate on life cycle of *Ae. Aegypti*  
• Find life stages in water containers on property  
• Report of dengue cases in neighbourhood |
| **Neighbourhood as unit for intervention** | Work with app. 140 HH within recognizable subdivisions |
| **Consent of community leadership** | • Requisite to proceed  
• Need consent for every aspect of programme |
| **Intermediaries between implementers and communities (facilitators)** | Roles, backgrounds, recruitment and activities can vary |
| **Official vector control programme** | Government programme should be continued without interference |
| **Community volunteers** | • Use residents from communities where activities will take place.  
• All should receive training regarding mosquitoes and transmission, communication skills that include respect for other community members |
| **House to house visits** | • Regular schedule  
• Explain disease and life cycle of vector mosquito, engage households in control efforts (container dumping, covers on large containers, trash removal, personal protection clothing and habits) |
| **Neighbourhood shops** | Same procedures as house to house visits |
| **Schools** | In and out of school, children key in both countries |
| **Businesses, churches, clubs** | Diverse main agendas, all shared threat of dengue and need for mosquito control. Programme enlisted many organizations for mobilization activities. |
| **Collective events (varied by community)** | Wide range of publicity and mobilization events included leaflets, posters, parades, songs, games, murals, t-shirts, street theatre, clean-up campaigns. |

*Note: Information for this table from Andersson et al., 2015.*
Brazil

The findings of Al-Muhandis were reinforced by the investigations of Caprara et al., (2015) who studied the impact and social participation in dengue control in northeastern Brazil. A cluster randomized controlled trial was designed by comparing 10 intervention clusters with 10 control clusters where routine vector control activities were conducted. The intervention included: community workshops; community involvement in clean-up campaigns; covering the elevated containers and in-house rubbish disposal without larviciding; mobilization of schoolchildren and senior inhabitants; and distribution of information, education and communication (IEC) materials in the community.

They found that differences in terms of social participation, commitment and leadership were present in the clusters. Social participation was fragile in locations (1) with nonexistent community organizations or (2) in neighbourhoods with either a history of violence or (3) very well-off and privileged groups. Based on results they emphasized that *Aedes aegypti* control requires the coordinated involvement of various sectors. These sectors include education, sanitation and street cleaning, culture, tourism, transport, construction and public safety; also partners from the private sector and organized society have to be included.

Alves et al., (2016) investigated the knowledge of users of primary healthcare services living in Ribeirão Preto (Brazil) about dengue and its vector. They conducted a cross-sectional survey of 605 people following a major dengue outbreak in 2013. Television was the main source of information about dengue (87.8 per cent), followed by pamphlets/posters (41.8 per cent), Internet (17.5 per cent), hospitals and health units (17.4 per cent), radio (12.2 per cent), newspapers (9.7 per cent), children’s schools (5.6 per cent), friends (4.6 per cent), relatives (4.3 per cent), schools, colleges, or faculty (4 per cent), and church or religious groups (2.2 per cent). The percentage of respondents who cited the Internet as an information source ranged from 0 per cent (illiterate) to 45.6 per cent (university educated). The results emphasized the relevance of health education programmes, the continuous promotion of educational campaigns in the media, the role of television as a source of information, and the importance of motivating the population to control the vector.

The Philippines

Espino et al., (2012) examined the ecological and social factors underlying the success of disease control. They examined responses to introducing water container management to control dengue vectors in two diverse communities in Masagana City (suburb of Manila, the Philippines): Village A (gated community) and Village B (informal settler community). The roll-out of the intervention was performed by the study team, dengue control personnel and local health workers. A behavioural change framework was used to describe the community responses to the introduction of a new vector control intervention, household water container management.

The targeted behaviour change (outcome indicator of this study) particularly at the household level (i.e., management of water containers) was not achieved during this project lifetime. Local government leadership was lacking in Masagana City. The political environment, social and economic differences in the two urban communities, and their take-up of new dengue control strategies affected attempts at introducing new interventions for dengue control. In retrospect, they concluded they should have adopted a strategy that negotiated socially responsible leadership from the Masagana city government, households in Village A and the homeowners’ association.

Thailand

In Thailand, no significant impacts were reported in a cRCT using a combination of *Mesocyclops aspericornis* (copepods), *Bacillus thuringiensis var. israelensis* toxins (Bti sacs), screen net covers (MosNet®), mosquito traps (MosHouse®), and portable vacuum aspirators (MosCatch™).
Cambodia and Laos

The WHO Western Pacific Region conducted a project to demonstrate benefits of integrated vector management for the control of Aedes in Cambodia and Laos. Results of that project, along with an overview of the communication plan to engage residents, were published in 2013.

The Western Pacific Region report describes a promising, low-cost, year-round vector control measure that is feasible to implement, is acceptable and safe to the public and, once established, has minimal recurring costs. Cambodia and the Lao People’s Democratic Republic participated in an intervention research project using IVM to determine whether households would accept the use of guppy fish in their large water storage jars, tanks and drums to control mosquito larvae and pupae, and if development of effective guppy distribution programmes was feasible.

The project teams used the Communication for Behavioral Impact planning tool of the WHO in developing the framework for delivering the interventions to selected villages.

The project results indicate that the pilot interventions were effective and successful in mobilizing communities to establish and maintain the guppy fish intervention, and in obtaining high levels of community acceptance of the fish in drinking water containers.

Step 1: Defining the preliminary behavioural objectives
Step 2: Conduct a rapid situational analysis
Step 3: Define the behavioural and communication objectives
Step 4: Design an overall strategy
Step 5: Develop detailed plans of action and a budget
Step 6: Monitoring interventions
Step 7: Evaluate once the outbreak is over


India

In India, Arunachalam et al., (2012) studied community-based control of Aedes aegypti. In the intervention clusters, Aedes control was carried out using a community-based environmental management approach like the provision of water container covers through community actors, clean-up campaigns and the dissemination of dengue information through schoolchildren.

Community involvement and the partnership among stakeholders (particularly women’s self-help groups) worked well. After 10 months of intervention, the pupae per person index was significantly reduced to 0.004 pupae per person from 1.075 in the intervention clusters compared to control clusters. There were also significant reductions in the entomological indices: the house index was reduced to 4.2 per cent, the container index to 1.05 per cent, and the Breteau index to 4.3 from the baseline values of 19.6, 8.91, and 30.8 in the intervention arm. They concluded a community-based approach, together with other stakeholders that promoted interventions to prevent dengue vector breeding, led to a substantial reduction in dengue vector density.

The Government of India National Vector Borne Disease Control Programme uploaded the Strategy and Plan of Action for Effective Community Participation for Prevention and Control of Dengue on its website in June 2016. This is a 45-page manual detailing methods communities should use for control of Aedes vectors of dengue. The manual includes messages to be used in IEC communication materials, record keeping logs and reporting formats, and a roll-out plan for engagement.

The Strategy document makes it clear that community participation and empowerment are the most important elements of the IVM strategy. It allows the local population to drive effective prevention of the disease. Since no specific antiviral treatment or vaccine against dengue is available, modification of individual behaviour is essential in mosquito-control initiatives. This means that individual households must accept
responsibility for the control of mosquitoes in their surroundings. Vertical vector control programmes may be ineffective if communities are not active partners in the control actions. A successful, sustainable vector control programme must involve a strong partnership between the government and community. Public participation is necessary at various stages in the local vector control strategy, in assessing the community’s problems and needs, in planning and implementing activities and in monitoring and evaluation.

Table 11 provides examples that demonstrate the effectiveness and need for community participation and not just household education or individual actions.

Table 11. Interventions against vector borne disease that could be initiated outside the health sector

<table>
<thead>
<tr>
<th>Intervention</th>
<th>Ministries or organizations involved in implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Health education and promotion</td>
<td>Schools, ministry of education, work places, the media (TV, radio, Internet), drama groups, NGOs, religious and community groups</td>
</tr>
<tr>
<td>LLINs, IRS, insecticide-treated sheeting or tents</td>
<td>NGOs, United Nations, vector borne disease control programmes, private sector, ministry of tourism, women's groups</td>
</tr>
<tr>
<td>House improvements and screening</td>
<td>Ministry of housing, NGOs, community members</td>
</tr>
<tr>
<td>Drainage</td>
<td>Department of public works, local government</td>
</tr>
<tr>
<td>Drain clearance</td>
<td>Youth groups who collect rubbish to sell, community groups</td>
</tr>
<tr>
<td>Drying out of breeding sites</td>
<td>Department of forestry, local government, community groups</td>
</tr>
<tr>
<td>Swampland restoration</td>
<td>Department of the environment</td>
</tr>
<tr>
<td>Removal of obsolete concrete water storage containers</td>
<td>Department of public works, contractor, local government</td>
</tr>
<tr>
<td>Filling and levelling</td>
<td>Department of public works, local government</td>
</tr>
<tr>
<td>Maintenance of irrigation channels or flushing</td>
<td>Farmers, ministry of agriculture, irrigation authority</td>
</tr>
<tr>
<td>Removal of vegetation from the edges of water bodies</td>
<td>Farmers, community members</td>
</tr>
<tr>
<td>Intermittent irrigation</td>
<td>Farmers, ministry of agriculture, irrigation authority</td>
</tr>
<tr>
<td>Improved housing</td>
<td>NGOs, microfinance initiatives, department of housing</td>
</tr>
<tr>
<td>Larval surveys and application of larvicides</td>
<td>Schools, community groups, municipal corporations, public health staff, farmers</td>
</tr>
<tr>
<td>Improvement of environmental sanitation</td>
<td>NGOs, department of public works, local government</td>
</tr>
<tr>
<td>Water supply and sanitation</td>
<td>Ministry of water resources, ministry of environment and sanitation, NGOs</td>
</tr>
<tr>
<td>Social and environmental responsibility, e.g., tyre disposal</td>
<td>Private companies</td>
</tr>
<tr>
<td>Solid waste and container disposal</td>
<td>Rubbish collectors, local government, youth groups, industry</td>
</tr>
<tr>
<td>Insecticide-treated cattle</td>
<td>Farmers, ranch owners, veterinary services</td>
</tr>
<tr>
<td>Topical insecticide or insecticide-treated collars on dogs</td>
<td>Dog owners, veterinary services or ministry of livestock, local municipalities</td>
</tr>
<tr>
<td>Culling of reservoir animals</td>
<td>Community groups, veterinary services, local municipalities</td>
</tr>
</tbody>
</table>
WHO provides fact sheets on major vector borne diseases that include recommendations for prevention and control (http://www.who.int/mediacentre/factsheets/en/). Each disease has specific approaches tailored to use the best practices that protect individuals and communities in the context of the different control technologies available. The following information was taken from the WHO factsheets.

**Disease Prevention**

**Dengue prevention**

At present, the main method to control or prevent the transmission of dengue virus is to combat vector mosquitoes by:

- preventing mosquitoes from accessing egg-laying habitats by environmental management and modification;
- disposing of solid waste properly and removing artificial man-made habitats;
- covering, emptying and cleaning of domestic water storage containers on a weekly basis;
- applying appropriate insecticides to water storage outdoor containers;
- using of personal household protection such as window screens, long-sleeved clothes, insecticide treated materials, coils and vaporizers;
- improving community participation and mobilization for sustained vector control;
- space spraying insecticides during outbreaks as one of the emergency vector control measures;
- active monitoring and surveillance of vectors to determine effectiveness of control interventions.

**Yellow fever prevention**

**Vaccination**

Vaccination is the most important means of preventing yellow fever. In high-risk areas where vaccination coverage is low, prompt recognition and control of outbreaks using mass immunization is critical for preventing epidemics. It is important to vaccinate most (80 percent or more) of the population at risk to prevent transmission in a region with a yellow fever outbreak.

Several vaccination strategies are used to protect against outbreaks: routine infant immunization; mass vaccination campaigns designed to increase coverage in countries at risk; and vaccination of travelers going to yellow fever endemic areas.

The yellow fever vaccine is safe and affordable and a single dose provides life-long protection against yellow fever disease. A booster dose of yellow fever vaccine is not needed. There have been rare reports of serious side-effects from the yellow fever vaccine. The rates for these severe ‘adverse events following immunization’, when the vaccine provokes an attack on the liver, the kidneys or on the nervous system, leading to hospitalization, are between 0.4 and 0.8 per 100,000 people vaccinated.
The risk is higher for people over 60 years of age and anyone with severe immunodeficiency due to symptomatic HIV/AIDS or other causes, or who have a thymus disorder. People over 60 years of age should be given the vaccine after a careful risk-benefit assessment.

People who are usually excluded from vaccination include:

- infants aged less than 9 months, except during an epidemic when infants aged 6-9 months, in areas where the risk of infection is high, should also receive the vaccine;
- pregnant women – except during a yellow fever outbreak when the risk of infection is high;
- people with severe allergies to egg protein;
- people with severe immunodeficiency due to symptomatic HIV/AIDS or other causes, or who have a thymus disorder.

In accordance with the International Health Regulations, countries have the right to require travellers to provide a certificate of yellow fever vaccination. If there are medical grounds for not getting vaccinated, this must be certified by the appropriate authorities. The IHR are a legally binding framework to stop the spread of infectious diseases and other health threats. Requiring the certificate of vaccination from travellers is at the discretion of each State Party, and it is not currently required by all countries.

**Mosquito control**

The risk of yellow fever transmission in urban areas can be reduced by eliminating potential mosquito breeding sites by applying larvicides to water storage containers and other places where standing water collects. Insecticide spraying to kill adult mosquitoes during urban epidemics can help reduce the number of mosquitoes, thus reducing potential sources of yellow fever transmission.

Historically, mosquito control campaigns successfully eliminated *Aedes aegypti*, the urban yellow fever vector, from most of Central and South America. However, *Aedes aegypti* has recolonized urban areas in the region, raising a renewed risk of urban yellow fever. Mosquito control programmes targeting wild mosquitoes in forested areas are not practical for preventing jungle (or sylvatic) yellow fever transmission.

**Chikungunya prevention**

The proximity of mosquito vector breeding sites to human habitation is a significant risk factor for chikungunya as well as for other diseases that these species transmit. Prevention and control relies heavily on reducing the number of natural and artificial water-filled container habitats that support breeding of the mosquitoes. This requires mobilization of affected communities. During outbreaks, insecticides may be sprayed to kill flying mosquitoes, applied to surfaces in and around containers where the mosquitoes land, and used to treat water in containers to kill the immature larvae.

For protection during outbreaks of chikungunya, clothing which minimizes skin exposure to the day-biting vectors is advised. Repellents can be applied to exposed skin or to clothing in strict accordance with product label instructions. Repellents should contain DEET (N, N-diethyl-3-methylbenzamide), IR3535 (3-[N-acetyl-N-butyl]-aminopropionic acid ethyl ester) or icaridin (1-piperidinecarboxylic acid, 2-(2-hydroxyethyl)-1-methylpropylester). For those who sleep during the daytime, particularly young children, or sick or older people, ITNs afford good protection. Mosquito coils or other insecticide vaporizers may also reduce indoor biting. Basic precautions should be taken by people travelling to risk areas and these include use of repellents, wearing long sleeves and pants and ensuring rooms are fitted with screens to prevent mosquitoes from entering.
**Zika prevention**

Protection against mosquito bites is a key measure to prevent Zika virus infection. This can be done by wearing clothes (preferably light-coloured) that cover as much of the body as possible; using physical barriers such as window screens or closing doors and windows; sleeping under mosquito nets; and using insect repellent containing DEET, IR3535 or icaridin according to the product label instructions. Special attention and help should be given to those who may not be able to protect themselves adequately, such as young children, the sick or elderly. Travellers and those living in affected areas should take the basic precautions described above to protect themselves from mosquito bites.

It is important to cover, empty or clean potential mosquito breeding sites in and around houses such as buckets, drums, pots, gutters and used tyres. Communities should support local government efforts to reduce mosquitoes in their locality. Health authorities may also advise that spraying of insecticides be carried out.

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**Indoor spraying with residual insecticides**

IRS is a powerful way to rapidly reduce malaria transmission. Its full potential is realized when at least 80 percent of houses in targeted areas are sprayed. Indoor spraying is effective for three to six months, depending on the insecticide formulation used and the type of surface on which it is sprayed. In some settings, multiple spray rounds are needed to protect the population for the entire malaria season.

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**Antimalarial drugs**

Antimalarial medicines can also be used to prevent malaria by eliminating the malaria parasite from the human host thereby reducing the malaria parasite reservoir. When there are no malaria gametocytes for the mosquito to acquire in its blood meal then transmission will effectively be curtailed even if a person is bitten by an anopheline. There is currently no fully effective malaria vaccine available, even as there are a number of candidates at various trial stages.

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**Malaria prevention**

Vector control is the main way to prevent and reduce malaria transmission. If coverage of vector control interventions within a specific area is high enough, then a measure of protection will be conferred across the community.

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**Insecticide-treated mosquito nets**

LLINs are the preferred form of ITNs for public health programmes. In most high transmission settings, WHO recommends LLIN coverage for all people at risk of malaria (universal coverage). The most cost-effective way to achieve this is by providing LLINs free of charge, to ensure equal access for all. In parallel, effective behaviour change communication strategies are required to ensure that all people at risk of malaria sleep under an LLIN every night, and that the net is properly maintained.

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**Japanese encephalitis prevention**

Safe and effective Japanese encephalitis vaccines are available to prevent disease. WHO recommends having strong Japanese encephalitis prevention and control activities, including immunization in all regions where the disease is a recognized public health priority, along with strengthening surveillance and reporting mechanisms. Even if the number of confirmed cases is low, vaccination should be considered where there is a suitable environment for the virus transmission. There is little evidence to support a reduction in Japanese encephalitis disease burden from interventions other than the vaccination of humans. There are four main types of Japanese encephalitis vaccines currently in use: inactivated mouse brain-derived vaccines, inactivated Vero cell-derived vaccines, live attenuated vaccines and live recombinant vaccines.
UNICEF has a key role to play in vector control across a variety of areas ranging from procurement and supply to communication for development.

Taking on vector control would be a challenge for UNICEF but the reward would be significant in terms of child protection and community improvement especially as many of the diseases spread by mosquitoes do not have vaccines or drugs to cure infections and must rely entirely on prevention (for e.g., the continued outbreaks of different dengue serotypes confound protection by vaccines, and vector control remains the only viable alternative to prevent outbreaks). The unexpected explosion of Zika virus in different geographic regions simultaneously is a case in point, showing that vector borne transmission dynamics are complicated and the factors leading to outbreaks are usually poorly understood. Climate changes, rapid urbanization without proper infrastructure, high human population densities and disjointed organizational societies create the perfect environment to be exploited by such well-adapted mosquitoes as *Aedes, Anopheles* and *Culex*.

Research has shown that clinical outbreaks start well after (lag) the buildup of mosquito populations. A vector borne epidemic smolders before exploding. If high-quality routine mosquito indicator monitoring is maintained in communities and there is sufficient capacity to analyse and respond to data, there should be sufficient forewarning so that preventative vector control measures can contain potential epidemics.

The techniques for monitoring mosquitoes are known and can be handled by volunteers in communities. Many of the preventative measures that reduce population build-up can be handled by cooperative efforts of the municipality, community groups and individual residents. Long-term prevention, such as house screening, drainage modification and large-scale source reduction can be accomplished with federal or district resources and regulations. Preparing plans of action can be encouraged and developed with leadership from UNICEF across its various sectoral interventions, in particular, health, WASH, emergencies, communication for development and education. More importantly, successful vector control can be achieved by sustained evaluation of the combination of methods customized at the local level for the local vectors and transmission cycles.

CONCLUSION:
The case for increasing UNICEF’s capacity to support vector control interventions
Vector control is a complicated exercise requiring action by every aspect of society from national governments to municipalities, health centres to schools, and from households to, most importantly, the communities themselves. Prevention, control and elimination of vector borne diseases is thus a shared responsibility across all levels, from community members to policy makers to other stakeholders and requires the concerted action of all. The success and sustainability of vector control interventions depends on harnessing social capital and resources available throughout these areas and in particular at the community level. Local knowledge and skills (cultural capital) can be capitalized on to support effective, sustainable, locally appropriate and feasible vector control solutions.

In terms of procurement and supply, UNICEF is already a key player in terms of the provision of LLINs and support to countries for their effective delivery, and previously in the supply of chemical larvicides to Guinea worm eradication programmes. The agency is also investing in water, sanitation and hygiene projects that have potential to include identification of source reduction or coverage to environmental manipulation by improved drainage or house screening. In terms of community mobilization and participation, members of UNICEF are already working with communities on other programmes and can identify key influencers and organizers to support community mobilization efforts around specific vector control and transmission situations. Education programmes are actively bringing WASH training to school children. UNICEF also has a strong comparative advantage in terms of its influence on government policies and can use that to increase awareness of critical health issues – including making the case that investment in vector control requires substantially less expenditure than care and support required when outbreaks occur.

The impact of vector borne diseases on children and their communities is dramatic and often lethal. UNICEF has a role to play in ensuring there is widespread attention to vector control across a diverse range of activities.
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ADDITIONAL READING
Articles not cited that provide additional supporting evidence


