HOUSES OF PARLIAMENT
PARLIAMENTARY OFFICE OF SCIENCE & TECHNOLOGY

POSTNOTE

Number 597 April 2019

Climate Change and Vector-Borne Diseases in Humans in the UK

A consequence of long-term alterations to the UK climate is changes to populations of native and invasive non-native species, including the prevalence of disease-transmitting species, such as ticks or mosquitoes. This POSTnote summarises the latest data on vector-borne disease in the UK, explores how climate may influence the geographical distribution of species, examines the consequences for public health, and explores potential adaptation and mitigation strategies.

Overview

- Vector-borne diseases are transmitted by organisms, such as ticks and mosquitoes.
- The UK has both native and invasive non-native vectors. The distribution of these species is changing across Europe.
- The causes of vector distribution change are complex and interlinked, but climate change plays a key role, especially in mosquito distribution.
- Tick-borne diseases are more susceptible to changes in landscape and host population density. These factors are correlated with the spread of Lyme disease.
- Surveillance coverage and methods vary for vector species; there is consensus that UK surveillance requires improvement.
- Addressing knowledge gaps and managing vector populations, alongside improved public awareness are important factors in tackling vector-borne diseases.

Background

A vector is an organism that carries and transmits disease between humans, animals and plants. Vector-borne diseases (VBDs) such as malaria and dengue fever, account for approximately 17% of infectious diseases and more than 700,000 deaths globally.[1] Vectors of concern in the UK are ticks and mosquitoes which are capable of transmitting VBDs to people.[2,3] For example, ticks are vectors for Lyme disease. There are currently 20 native tick species and 36 native mosquito species in the UK, but relatively few pose a threat to human health.[4,5]

Recent surveillance has recorded changes in vector distribution patterns across Europe, including identification of invasive non-native species in the UK.[6] For example, a dengue virus vector, the Asian tiger mosquito, was originally from southeast Asia but was first recorded in southern England in 2016.[2] This expansion of vector range, or conditions that lead to an increased ability of native vectors to transmit disease, is a risk for the UK.[6] Tick monitoring shows that species distribution is changing, and concurrently shifting the pattern of Lyme disease cases.[7] Vector establishment, however, does not always mean spread of the VBDs they can carry, as other factors, such as vector biting behaviour, affects their capacity to transmit disease.[8]

There is increasing policy interest in the health impact of changing vector distributions and biosecurity measures to protect public health in the UK. The causes of vector distribution changes are complex and are influenced by land use, globalisation and other socio-economic factors, but climate change is considered a main contributory factor.[9] The extent to which climate change affects vector distribution depends on the vector and its hosts.[6] Theoretical models predicting the influence of climate variables on the geographical distribution and size of vector populations are in development, but these include uncertainties and models do not cover all species. The World Health Organization (WHO) has highlighted

international interest in predicting and limiting geographical distributions of vectors.[9]

Vector-borne diseases in the UK

VBDs are spread by vectors feeding on hosts. Vectors use hosts for feeding and development (Box 1). Although vector abundance is a good predictor of VBD presence or risk, other factors such as vector behaviour also influences the likelihood of disease transmission.[10] In addition, the disease-causing microorganism (pathogen) itself has to be present and may be restricted by a range of factors. The presence of vectors, therefore, does not necessarily mean presence of VBD.[10]

Mosquito and mosquito-borne diseases

Non-native species

No mosquito-borne diseases of humans are circulating in the UK, although historically both malaria and yellow fever have been present.[11] Pathogens within invasive mosquitoes were eliminated from the UK after the 1940s through extensive land use changes that drained wetlands.[12,13] Invasive species are potential vectors of human mosquito-borne diseases in the UK.[14] The mosquito *Aedes albopictus* is established in the Mediterranean basin and has been identified in at least 25 European countries, including the UK.[11] *Ae. albopictus* is a vector for dengue virus and chikungunya virus, both of which may cause serious or life-threatening infections. The UK climate is favourable for *Ae. albopictus* to establish breeding populations.[6] The insect is spread by movement of adult mosquitoes in vehicles or in water-filled containers, such as tyres, which provide a favourable habitat for the mosquito's larval stage.[15] The mosquito, *Aedes aegypti* is also a dengue virus and chikungunya virus vector, although current cold UK temperatures means it is not established in the UK.[6] The risks of VBDs from all these species are detailed in Table 1.

Native species

The UK has 36 native mosquito species and most do not transmit diseases.[5] However, the *Culex* mosquitoes include known disease vectors, and the main European vector for West Nile virus (WNV). WNV is a bird-associated virus that has caused around 1,600 deaths in the US.[16] Within this group, *Culex modestus* is capable of biting humans and birds.[17] It has been identified in southern England, with evidence of it spreading in the UK.[17] A growing concern is whether other native *Culex* species will become more abundant in areas of high human density and thus change the risk of WNV.[17] Although other UK mosquito vectors, such as *Anopheles*, can also transmit malaria in a controlled laboratory setting, the translation of this to present UK environmental conditions is not a high risk (Table 1).[14]

Tick and tick-borne diseases

Of the 20 endemic tick species, *Ixodes ricinus* is the greatest public health concern for the UK.[18] *I. ricinus*, the sheep tick, is the vector for the *Borrelia* bacteria that causes Lyme disease, as well as tick-borne encephalitis (TBE) virus.[4] Lyme disease is the most common VBD in the UK with around 3,000 new cases reported annually in England and Wales.[22] Tick-borne encephalitis is a severe viral infection, however, and is currently only found in other European countries, such as Switzerland and the Netherlands, with low risk of the virus getting to the UK.[23,24] Other tick-borne disease threats include Crimean Congo Haemorrhagic Fever (CCHF), spread by *Hyalomma* ticks which are endemic to eastern and south-eastern Europe and currently pose a low risk to the UK.[4]

Box 1. Vector-host interactions

A host typically provides nourishment and shelter for an infected vector.[19] Some vectors, such as ticks, use additional, secondary hosts during asexual/larval stages.[20] For ticks, human infections occur when a tick vector bites humans instead of an animal host, such as birds or rodents.[19] Mosquitoes take blood meals only in the adult stage and a female may feed on one to several hosts in her lifetime. Ticks tend to feed once per stage in the larval, nymphal and adult stages, each time on a different host. Hosts generally are used:

- by vectors to complete developmental stages and for feeding
- for short periods of vectors' life cycles.

Some infected vectors use dead-end hosts, such as ticks using deer species. Dead-end hosts allow vector development but do not transmit the disease.[21]

Burden of disease

In the UK, Lyme disease is not a notifiable disease and so the Public Health England (PHE) figure of 3,000 new cases annually is likely to be an underestimate.[25] Lyme disease hot spots include southern England and the Scottish Highlands, but cover other UK areas.[21] According to NICE, there is no robust epidemiological evidence on Lyme disease in the UK population.[25] The available data suggest there are areas of higher and lower prevalence in the UK but there are many knowledge gaps.[25] Patients report a characteristic rash and 'flu-like' symptoms.[26] If not detected and treated quickly with antibiotics, it can sometimes lead to more serious neurological and cardiac conditions.[26] Patients treated with antibiotics usually recover over 2-4 weeks. Patients are tested for antibodies against Lyme disease, but issues with the sensitivity of diagnosis are expressed by some stakeholders such as Lyme Disease Action (LDA).[27,28]

Cases of other VBDs have not yet been reported in the UK, but this could change if invasive vector species become established (Table 1).[4] The burden of these diseases could be even greater; malaria and dengue virus are potentially life-threatening and carry a significant health burden.[1]

Vector-borne disease and climate change

Global climate change effects

There is consensus amongst academics that climate affects major aspects of VBD spread.[6] Vectors are usually geographically restricted, as a consequence of climate conditions, limiting diseases to certain countries or regions.[10] Human-caused climate change has led to seasonal variations and increases in mean temperatures.[29] This has led to consequent global changes in vector distributions, as seen with *Aedes* mosquitoes, that are exacerbated by globalisation of trade.[29] Although climate change will affect all VBDs, the extent to which it does so is vector-, host- and disease-dependent.[29] The effects of

climate change are interlinked with globalisation, land use and socio-economic factors and distinguishing between these can prove challenging.[6]

UK impact

In the UK, invasive mosquito species have been identified by PHE that were previously restricted to warmer, more tropical environments.[29] This is due to various factors, including increased international trade and travel.[30] As climate changes in the UK, permanent invasive species populations are likely to become established, particularly mosquito species.[6] Higher temperatures typically decrease the time it takes for mosquitoes to become infectious, potentially allowing more opportunities for transmission when feeding.[29] The current UK climate is already suitable for *Ae. albopictus,* but further rises in temperature could increase the months and areas in which these mosquitoes can be active.[31] Currently, models suggest a 1ºC average rise in mean temperature by 2030-2050 could lead to an approximate 1-2 week extension of adult mosquito activity in Southern England.[6]

Ae. aegypti and invasive malarial vectors could also become established if temperatures become warmer for extended periods of time.[6] According to PHE and models from the Met Office, other UK climate variables, such as humidity and rainfall, will also change leading to altered water availability influencing mosquito breeding levels.[29] Studies on the effect of climate change on VBDs are limited but it is well established that vectors are more likely to spread infection at higher mean temperatures.[6] However, extremely high temperatures will reduce transmission.[15] The precise effects are difficult to measure accurately; both laboratory and field studies are required but each has limitations.[32]

For ticks, PHE predicts that an increase in the number of ticks identified may lead to changing geographical distributions of tick-borne diseases.[33] Changes to the UK climate are likely to have a smaller impact on ticks than land use changes, especially woodland areas.[6] This is because tick populations are concentrated in wooded areas, and where there are high numbers of host populations such as deer or sheep.[33] Although not a main contributory factor for invasive ticks, climate change may affect the ability for invasive non-native ticks to establish populations in the UK.[4]

Modelling vector-borne disease

Models are used to describe a complex system with different variables and are useful to monitor and predict events. Vector distributions can be modelled in different ways, and the model chosen is usually dependent on data availability.[34] Higher temperatures speed up mosquito development, meaning they can potentially be infected earlier and transmit infection.[35] However, the role of temperature is complex as it also shortens the mosquito's life span.[35] In comparison, ticks are longer lived and feed sparingly during their life, meaning temperature has less effect.[33] However, infected ticks are highly sensitive to changing moisture levels and habitat availability.[33]

Table 1. Vector-Borne Disease in the UK – summary of risk identified by Public Health England[2]

BD	Vectors responsible	Climate change effect on vectors	Risk of VBD
dengue fever or chikungunya	*Ae. albopictus, Ae. aegypti* mosquitoes	Increasing temperatures and precipitation will allow mosquitoes to colonise more urban areas.	*
West Nile fever	*Culex* mosquitoes	Creation of wetland in rural and urban areas may increase infected populations.	Low
malaria	*Anopheles* mosquitoes	Higher temperatures will allow for parasite development.	Low
Lyme disease	*Ixodes ricinus* ticks	Seasonal activity of ticks affected, climate may also affect hosts. Range and distribution affected.	High/current cases present
Tick-borne encephalitis	*I. ricinus* ticks	Feeding, range and distribution affected.	*

*Indicates that current risk assessments by Public Health England's Human Animal Infections and Risk Surveillance group are being undertaken but there are currently no known cases.

How vectors respond to temperature fluctuations is also important to model as this can change the prediction entirely.[15] Climate variables such as humidity and precipitation also affect vector distribution, but these are more difficult to measure.[15] More recent research models of vector distribution are increasingly based on a wider combination of variables.[15]

Current surveillance systems

Tick surveillance system

The UK's Tick Surveillance Scheme (TSS) began in 2005 and is run by PHE.[18] The TSS aims to provide researchers, policymakers and the public with information about native and non-native invasive tick species, distribution and the risk they may pose to public health. It collects and records tick distributions across England and Wales from samples collected by PHE and from those sent by members of the public, health professionals and charities, with data made publicly available on the National Biodiversity Network.[36,37]

Since 2005, the scheme has identified 10 invasive tick species from 15 countries which have entered the UK largely as a result of canine travel.[38] The TSS also aims to make the public aware of tick-borne diseases, such as Lyme disease, and the dangers of tick bites. It does this through the production of online guidelines and tick toolkits distributed to local authorities and other stakeholders.[18]

Mosquito surveillance system

PHE also runs a mosquito reporting system.[31] The scheme is not as widespread as the TSS, and mainly relies on PHE collecting specimens in locations of interest, although the

public is also encouraged to submit mosquitoes for identification. A routine method is to attract mosquitoes into traps.[5] Invasive mosquito traps are mostly based in southern England where the risk of these mosquitoes entering and establishing is greater, including near ports of entry.[5] However, traps for native mosquitoes are placed across England.

Adaptation and mitigation strategies

Combating VBD incursion into the UK requires a multi-faceted approach including: enhanced surveillance and monitoring to inform policy; public health actions such as immunisation; and a range of vector control measures to enhance biosecurity. Mitigating climate change effects are also seen by stakeholders as crucial to alleviate the problem.[39]

Short-term policy options

Surveillance strategies

A major concern for stakeholders is that the current level of national surveillance is inadequate.[14] Although passive tick and mosquito surveillance systems are in place, the increasing risk of VBD spread as a result of climate change and other factors has prompted stakeholders to comment that monitoring should be expanded.[14] It is suggested that nationwide active surveillance would ensure areas that do not have vectors are also monitored, which is especially important in outbreak scenarios.[40] Currently, there are several surveillance approaches with different systems, used across Europe.[41] The most cost-effective method may therefore be initially expanding surveillance to monitor areas most at risk across the UK, and the testing of vectors for pathogens.[5,18] PHE states that additional resources would be required to extend invasive mosquito surveillance to other parts of the UK.[42] One option is to focus on further collaborations between government agencies and academia, health professionals and veterinarians, which will enhance surveillance and improve the quality of data on species of interest in the UK.[43,44] In general, vectors and the environment are adapting continuously so future guidelines will also need to adapt. This is often difficult to predict, but increasing surveillance and research aids this process.

Citizen science and public awareness

This public involvement offers a relatively cheap way to collect data.[45] PHE invites the public to send specimens for analysis. This has already been effective for PHE but future strategies could expand citizen projects across the UK and increase data collection.[45] This data is subject to intrinsic bias, such as recording bias, but some of this can be managed using statistical methods.[46,47]

NICE, PHE and some campaign organisations such as Lyme Disease Action (LDA) have produced information resources for health professionals and the public to raise awareness of VBDs and provide advice on minimising health risks and appropriate care pathways.[27] More widespread communication, in the form of leaflets, engagement with local authorities, and enhanced educational tools for the public and health professionals could prove useful for lowering human exposure to vectors and treating bites appropriately.[43]

Long-term policy options

Vaccine development

Vaccination is considered one of the most cost-effective methods to prevent infectious disease.[48] Vaccine research and development is expensive and there are scientific challenges in developing vaccines for some infections.[49] There are currently vaccines for tick-borne encephalitis, yellow fever and dengue, but there are no vaccines for other VBDs.[50–52]

Other control methods

Since the removal of compulsory tick treatment for pets at UK borders, there has been a surge in invasive tick species identified in the UK.[53] The British Veterinary Association recommends reversing this change.[53] Where vaccines are not available, other strategies are used to manage vectors, such as insecticide-treated mosquito nets and vector control.[49,54] At present, the UK Biological Biosecurity strategy employs several approaches, from border inspections, to banning specific animal and plant imports.[55] The Lords Energy and Environment EU Sub Committee highlighted concerns about changes to UK legislation on biosecurity post-Brexit in 2018.[46] In the event of an outbreak, the UK Government has control arrangements that deal with managing potential scenarios.[57] Other government departments also invest in controlling health threats in developing countries.[55] Collaborations, such as the Innovative Vector Control Consortium, are researching new insecticide chemicals that are less harmful to the environment.[58]

Research funding and knowledge gaps

Developing models and other interventions rely on fundamental and comprehensive understanding of the biology of VBDs, their respective vectors and the relationship with complex and interacting environmental factors. Publicly funded research projects on different aspects of VBDs seek to further the understanding of infection and risk to humans. However, researchers in academia and PHE are calling for increased focus and funding for more comprehensive surveillance, especially of tick species.[4] Further work to improve Lyme disease diagnostic tests is also recommended by LDA.[27]

Genetically modified insects

New technologies offer other approaches, notably genetically modified (GM) insects.[59] GM mosquitoes are engineered to carry a lethal change to their DNA that makes them unable to survive in the wild, or are replaced by populations that cannot transmit pathogens as is seen in techniques involving the Wolbachia bacteria.[59,60] There is uncertainty about the feasibility or usefulness of GM mosquitoes, as highlighted by the Lords Science and Technology Committee in 2015.[61] Furthermore, there are ethical concerns.[59] However, GM mosquitoes have been trialled in the wild including in Florida and Brazil.[62,63] The potential of this technology is recognised by WHO which is considering it as part of their VBD control strategy.[64,65]

POST is grateful to Jonida Tafilaku for researching this briefing, to the Medical Research Council's Doctoral Training Programme for funding her parliamentary fellowship, and to all contributors and reviewers. For further information on this subject, please contact the co-author, Dr Sarah Bunn.

Endnotes

1. World Health Organization, Global Vector Control Response 2017–2030, October 2017
2. The Human Animal Infections and Risk Surveillance (HAIRS) Group 2017 Report, September 2018
3. Climate Change and Infectious Disease in Humans in the UK, POSTbrief 16, Parliamentary Office of Science and Technology, December 2015
4. Cull, B. *et al.* (2018). Surveillance of British ticks: An overview of species records, host associations, and new records of Ixodes ricinus distribution. *Ticks Tick Borne Dis*, Vol 9, 605–614
5. Mosquitoes: surveillance and recording, Public Health England
6. Medlock, J. M. *et al.* (2015). Effect of climate change on vector-borne disease risk in the UK. *The Lancet Infectious Diseases*, Vol 15, 721–730
7. Millins, C. *et al.* (2016). Heterogeneity in the abundance and distribution of Ixodes ricinus and Borrelia burgdorferi (sensu lato) in Scotland: implications for risk prediction. *Parasites & Vectors*, Vol 9:595
8. Paaijmans Krijn P. *et al.* (2012). Warmer temperatures reduce the vectorial capacity of malaria mosquitoes. *Biology Letters*, Vol 8, 465–468
9. Githeko, A. K. *et al.* (2000). Climate change and vector-borne diseases: a regional analysis. *Bulletin of the World Health Organization*, 78(9)
10. Rogers, D. J. *et al.* (2006). Climate change and vector-borne diseases. *Adv. Parasitol.*, Vol 62, 345–381
11. Medlock, J. M. *et al.* (2017). Detection of the invasive mosquito species Aedes albopictus in southern England. *The Lancet Infectious Diseases*, Vol 17, 140
12. Hutchinson, R. A. *et al.* (2006). Malaria and deaths in the English marshes. *Lancet*, Vol 367, 1947–1951
13. Chin, T. *et al.* (2004). Malaria in the UK: past, present, and future. *Postgraduate Medical Journal*, Vol 80, 663–666
14. Medlock, J. M. *et al.* (2018). Assessment of the Public Health Threats Posed by Vector-Borne Disease in the United Kingdom (UK). *Int J Environ Res Public Health*, Vol 15 (10)
15. Metelmann, S. *et al.* (2019). The UK's suitability for Aedes albopictus in current and future climates. *Journal of the Royal Society Interface*, 13 March
16. (2018). Final Cumulative Maps and Data, West Nile Virus Disease, Centres for Disease Control and Prevention
17. Golding, N. (2012). West Nile virus vector Culex modestus established in southern England. *Parasites & Vectors*, 5:32
18. Tick awareness and the tick surveillance scheme. Public Health England
19. Wilson, A. J. *et al.* (2017). What is a vector? *Philos Trans R Soc Lond B Biol Sci*, Vol 372
20. Randolph, S. E. (1998). Ticks are not Insects: Consequences of Contrasting Vector Biology for Transmission Potential. *Parasitol. Today (Regul. Ed.)*, Vol 14, 186–192
21. Medlock, J. M. *et al.* (2017). Detection of Lyme disease causing Borrelia burgdorferi s.l. in questing Ixodes ricinus ticks on Jersey. *Journal of Infection*, Vol 75, 464–465.
22. Lyme Disease: Signs and Symptoms, 2018. (First Published 2015) Public Health England
23. Ticks in Switzerland: risk areas and tick protection - www.ch.ch.
24. Annual Epidemiological Report for 2016: Tick-borne encephalitis, European Centre for Disease Prevention and Control, July 2018
25. Lyme disease, Guidance and Guidelines, National Institute for Health and Care Excellence
26. Lyme disease, National Health Service
27. Lyme Disease Action, Lyme Disease in the UK - Briefing for MPs, November 2016
28. Kemp P.F. (2018). Re: Lyme disease: summary of NICE guidance. Diagnosis: do the guidelines pass the test?, *British Medical Journal* 2018;361;k1261
29. Baylis, M. (2017). Potential impact of climate change on emerging vector-borne and other infections in the UK. *Environ Health*, Vol 16 (Suppl 1): 112
30. European Commission on Agriculture, Fortieth Session (2017). The effect of climate change on animal diseases, trade and food security in the REU region.
31. Distinguishing *Aedes albopictus*, the Asian Tiger mosquito, from native British mosquitoes. Public Health England
32. Lambrechts, L. *et al.* (2009). Shifting priorities in vector biology to improve control of vector-borne disease. *Trop. Med. Int. Health*, Vol 14, No 12, 1505–1514
33. Medlock, J. M. *et al.* (2013). Driving forces for changes in geographical distribution of Ixodes ricinus ticks in Europe. *Parasites & Vectors*, Vol 6, 1.
34. Purse, B. V. *et al.* (2015). Tracking the distribution and impacts of diseases with biological records and distribution modelling. *Biological Journal of the Linnean Society*, Vol 115, 664–677.
35. Paaijmans, K. P. *et al.* (2013). Temperature variation makes ectotherms more sensitive to climate change. *Glob Chang Biol*, Vol 19, 2373–2380.
36. Biodiversity Auditing, POSTnote 490, Parliamentary Office of Science and Technology, March 2015
37. National Biodiversity Network
38. Hansford, K. M. *et al.* (2018). Potential risk posed by the importation of ticks into the UK on animals: records from the Tick Surveillance Scheme. *Veterinary Record*, Vol 182, 107
39. Limiting Global Warming to 1.5°C, POSTnote 594, Parliamentary Office of Science and Technology, February 2019
40. Fournet, F. *et al.* (2018). Effective surveillance systems for vector-borne diseases in urban settings and translation of the data into action: a scoping review. *Infect Dis Poverty*, Vol 7:99
41. Implementation of the Regional Framework for Surveillance and Control of Invasive Mosquito Vectors and Re-emerging Vector-borne Diseases 2014–2020: lessons learned and the way forward. Regional Office for Europe, World Health Organisation, September 2018
42. Medlock, J., Public Health England. Personal Communication 24/01/19.
43. UK Vector Borne Disease Research, Training and Infrastructure Landscape Survey Report. 24. Biotechnology and Biological Sciences Research Council
44. Countryside Survey
45. Palmer, J. R. B. *et al.* (2017). Citizen science provides a reliable and scalable tool to track disease-carrying mosquitoes. *Nat Commun*, Vol 8, 918
46. Hamer, S. A. *et al.* (2018). Contributions of citizen scientists to arthropod vector data in the age of digital epidemiology. *Current Opinion in Insect Science*, Vol 28, 98–104
47. Environmental Citizen Science, POSTnote 476, Parliamentary Office of Science and Technology, August 2014
48. Immunisation – Information for Immunisation Practitioners and other Health Professionals, Public Health England
49. Aggarwal, A. *et al.* (2018). Newer Vaccines against Mosquito-borne Diseases. *Indian J Pediatr*, Vol 85, 117–123.
50. Yellow Fever: The Green Book, Chapter 35. Public Health England
51. Tick-Borne Encephalitis: The Green Book Chapter 31, Public Health England
52. Dengue, NHS, 2016
53. British Veterinary Association Position on Pet Travel, August 2018, British Veterinary Association
54. Control strategies – Mosquito Vector Control. World Health Organization
55. UK Biological Security Strategy. July 2018, HM Government
56. Brexit: Plant and Animal Biosecurity. House of Lords European Union Committee, 21st Report of Session 2017-19, October 2018, HL Paper 191
57. Communicable Disease Outbreak Management, 2014, Public Health England
58. Innovative Vector Control Consortium
59. GM Insects and Disease Control, POSTnote 483, Parliamentary Office of Science and Technology, November 2014
60. Pereira, T. N. *et al.* (2018). Wolbachia significantly impacts the vector competence of Aedes aegypti for Mayaro virus. *Scientific Reports*, Vol 8, 6889
61. Genetically Modified Insects, House of Lords Science and Technology Committee, 1st Report of Session 2015-16, December 2015, HL Paper 68
62. Florida Keys Mosquito Control District, Oxitec OX513A Trial
63. Oxitec Launches Field Trial in Brazil for Next Generation Addition to Friendly™ Mosquitoes Platform, 24 May 2018, Oxitec
64. Progress and prospects for the use of genetically modified mosquitoes to inhibit disease transmission: World Health Organization, Geneva, Switzerland, 4-6 May 2009 : Report on planning meeting 1 : Technical consultation on current status and planning for future development of genetically modified mosquitoes for malaria and dengue control. World Health Organization
65. World Mosquito Program