World Health Organization
REGIONAL OFFICE FOR Europe

Manual on prevention of establishment and control of mosquitoes of public health importance in the WHO European Region

(with special reference to invasive mosquitoes)

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ABSTRACT

Introduction and establishment of invasive mosquito vectors have increased the threat of emerging and re-emerging vector-borne diseases such as dengue and chikungunya in the WHO European Region. *Aedes albopictus* and *Ae. aegypti*, in particular, have increased their geographical range and occurrence, while some native vectors have also spread into new areas. These problems highlight the need for countries to have systems in place for entomological surveillance and vector control. This manual provides practical guidance on vector control. Four scenarios are outlined, ranging from prevention of introduction and establishment of vectors, to control of vector populations and circulating disease pathogens and newly emerging diseases. State-of-the-art methods of control are described, accompanied by discussion of their effectiveness, application, use, and monitoring and evaluation. Strategies for planning and implementation are outlined for each scenario. Regulatory, legal and organizational aspects of vector control, and monitoring and evaluation are discussed.

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Contents

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Abbreviations

Ae.	*Aedes*
An.	*Anopheles*
Bti	*Bacillus thuringiensis israelensis*
Cx.	*Culex*
ECDC	European Centre for Disease Prevention and Control
EMCA	European Mosquito Control Association
EU	European Union
GVCR	Global Vector Control Response
IGR	insect growth regulator
IHR	International Health Regulations
s.l.	*sensu lato*, “in the broad sense”
s.s.	*sensu stricto*, “in the strict sense”
SIT	sterile insect technique
spp.	species (plural)
ULV	ultra-low volume
VBD	vector-borne disease

Executive summary

Vector-borne diseases (VBDs) pose a major threat to the health of societies around the world. They are caused by parasites, viruses and bacteria transmitted to human beings by mosquitoes, sandflies, triatomine bugs, blackflies, ticks, fleas, tsetse flies, mites, snails and lice. Major global VBDs affecting humans include malaria, dengue, lymphatic filariasis, Chagas disease, onchocerciasis, leishmaniasis, chikungunya, Zika virus disease, yellow fever, Japanese encephalitis and schistosomiasis. In the WHO European Region, VBDs such as leishmaniasis, West Nile fever, Crimean–Congo haemorrhagic fever, Lyme borreliosis and tick-borne encephalitis continue to cause a public health burden in a number of countries.

Introduction of invasive vector mosquitoes, together with the geographical expansion of some native vector mosquitoes, has substantially increased the threat of re-emerging VBDs in the European Region. Of most concern is the rapid expansion of the geographical range of *Aedes albopictus*, as well as reports of establishment of *Ae. aegypti* along coastal areas of the Black Sea region and on Madeira (Portugal). Recent local outbreaks of dengue and chikungunya on Madeira and in the Mediterranean basin serve as a stern reminder of the potential burden these developments may cause.

The problem of invasive vector mosquitoes suggests that countries should have adequate systems in place for entomological surveillance and vector control that enable them to reduce the threat of re-emerging VBDs. Detailed guidance is available for surveillance, but not for control, of invasive and native mosquitoes in Europe. This manual responds to the request from individual countries for practical guidance on vector control in the Region; it is also in line with the recently adopted Global Vector Control Response (2017–2030), which was passed by the World Health Assembly in 2017.

Four scenarios for prevention and control activities are outlined: (1) an invasive vector mosquito is not established, but there is risk of introduction; (2) an invasive vector mosquito has locally established itself within a small area; (3) an invasive vector mosquito has become widely established; and (4) a vector mosquito is implicated in local transmission of disease pathogens.

State-of-the-art methods of control are described, with a main focus on container-breeding *Aedes* species. These main methods of control are: source reduction; larviciding; screening of windows and doors; targeted residual spraying; and emergency space spraying. For each method, there is a detailed discussion of the available evidence concerning its effectiveness; methods of application; when and where it should be used; and how to monitor and evaluate it.

In the context of each of the four scenarios, strategies of implementation of vector control are discussed. Each discussion starts with situation analysis and decision-making, and then moves to selection of methods for prevention and control, identification of needs and resources, exploration of partners in implementation, and methods of monitoring and evaluation. Special attention is given to outbreak preparedness.

The final sections of the manual discuss regulatory aspects of vector control, particularly with respect to use of insecticides; legislation in support of preventive and control actions; and organizational aspects of vector control. It is proposed that an interministerial task force for vector control at country level is established, in line with the Global Vector Control Response.

1. Background

There have been numerous advances in public health that have led to a significant decline in many infectious diseases, or even their complete elimination. Only 100 years ago, such diseases were widespread, but with technological advances and socioeconomic improvements, many have been brought under control or can be managed at a low level of burden in many of the advanced economies. However – in spite of this progress – vector-borne diseases (VBDs) continue to place a heavy burden on societies. Examples of such VBDs are malaria, leishmaniasis and dengue, which have an annual incidence of millions of cases and cause more than a million deaths each year.

The WHO European Region, consisting of 53 Member States and stretching from Greenland to the Russian Federation and from the Mediterranean to the Baltic Sea (Fig. 1), is endemic for many VBDs. The wide variety in climate and topography, typical for such a vast and highly varied geographical region, provides rich biological niches for many different arthropod vectors as well as associated parasites and pathogens. Historically, these conditions led to a widespread distribution of VBDs in the Region, often with high prevalence.

Fig. 1. Map of the WHO European Region

After the disappearance of plague and yellow fever in past centuries, most VBDs were eliminated from western parts of the WHO European Region soon after the Second World War; in many eastern and southern parts of the Region, VBD elimination was achieved more recently or is still in progress. In 2016 the Region was declared free of indigenous malaria transmission. Leishmaniasis and dengue are no longer a major health problem in the Region (de Zulueta, 1973, 1998; Özbilgina et al., 2011; Gueye et al., 2016), but leishmaniasis is still endemic in parts of the Mediterranean and central Asian countries in the east of the Region (Dujardin et al., 2008); preventing outbreaks of dengue and other *Aedes*-borne arboviral diseases remains a concern.

There is growing evidence that climate change is linked to observed changes in VBD endemicity; this, in turn, is caused by shifts in vector distribution and expansion of vector species into geographical regions that were hitherto unsuitable for climatic reasons. These changes have led to the emergence of VBDs that were historically absent because of climatic unsuitability in areas where the current climate enables pathogen transmission by local vectors (Medlock et al., 2012). In other cases, invasive vector species have been able to survive under local environmental conditions and thus become established. The best example of these is *Ae. albopictus*, commonly known as the Asian tiger mosquito, an exotic species which has become firmly established in many countries of the WHO European Region (Cunze et al., 2016). Native mosquitoes can act as vectors of exotic pathogens; one example is *Culex pipiens*, which can transmit West Nile virus.

Several of the countries bordering the WHO European Region are endemic for VBDs: malaria, leishmaniasis and filariasis are still endemic in Afghanistan; Rift Valley fever is occasionally reported in Egypt; West Nile virus circulates seasonally in North African countries. The growing number of travellers moving between countries of the European Region and countries outside the Region that are endemic for various VBDs enhances the risk of disease importation. One example of this is an outbreak of chikungunya in Italy in 2007, when a traveller from India arrived with the virus and infected the local population of *Ae. albopictus*; this was the start of an outbreak of chikungunya with approximately 200 cases (Rezza et al., 2007; Angelini et al., 2008). Subsequently, autochthonous chikungunya cases in Europe were reported in 2010 and 2014, with the latest outbreaks in Italy and France in 2017 (Calba et al., 2017; Venturi et al., 2017). In the past decade, France has also experienced several cases of autochthonous dengue, with the latest cases in 2015 (Succo et al., 2016; Rousseau et al., 2017) and 2018. Spain also reported several cases of autochthonous dengue in 2018 (ECDC, 2018a).

These examples and recent evidence of the arrival and establishment of other invasive vectors and/or pathogens in the WHO European Region have caused public health concerns that need to be addressed. The invasion of exotic vectors would perhaps not be a reason for concern if they did not demonstrate any capacity to transmit disease agents. Lessons from the recent past have shown, however, that under European environmental conditions several mosquito species can act as disease vectors. Climate change, expected to cause an increase in average temperature and changing rainfall patterns, is likely to further increase the risk of VBDs, as the vectors benefit from longer phenological seasons, and conditions for vector competence improve with rising temperature (Patz et al., 2007; 2014).

This manual discusses the risks of disease transmission by invasive species and examines the measures that can be taken to prevent VBD transmission. It was prepared following publication of WHO's regional framework document for surveillance and control of invasive mosquitoes, and the strategic document on mosquito control published jointly by WHO and the European Mosquito Control Association (WHO, 2013b; WHO/EMCA, 2013). The manual responds to requests from Member States for practical guidance to assist them and their various programmes in operational planning for vector control in different settings. Transmission of exotic pathogens by local (endemic) mosquito species and its prevention are also discussed. The document is aligned with the requirements set out in WHO's *Global vector control response 2017–2030*, which was adopted by the World Health Assembly in May 2017 (WHO, 2017a).

2. Native and invasive mosquito vectors in the WHO European Region

In terms of both geography and climate, the WHO European Region is highly diverse. In the north and east, the climate is temperate; in the northwest, it is maritime; and in southern Europe, southern Turkey and Israel, it is Mediterranean. In temperate zones, winters are long and cold, while the summers can be very hot; the maritime zones enjoy relatively mild winters, and wet and mild summers; and the Mediterranean region is characterized by relatively mild winters and hot, dry summers. Adapted to this climatic variability, the mosquito species endemic to the Region are both numerous and diverse; some species occur all over the area, while others have a restricted distribution associated with a particular regional climate. For example, *Cx. pipiens pipiens* has an area-wide distribution, while *Anopheles sacharovi* is limited to the Black Sea coast, Azerbaijan and the Mediterranean.

Within the Region, a large number of native mosquito species have been listed as potential vectors of human and animal pathogens (ECDC, 2014). Historically, several species are known as vectors: *Cx. pipiens pipiens* is widely recognized as a local vector of West Nile virus (Fros et al., 2015); several species of the *An. maculipennis* complex (*An. atroparvus*, *An. labranchiae*, *An. maculipennis s.s.*, *An. messeae*, *An. sacharovi*) have frequently been documented as vectors of malaria [Sinka et al., 2010]; and *Cx. torrentium* has been incriminated as the vector of Ockelbo and Sindbis viruses (Francy et al., 1989). In several countries, transmission was formerly so widespread that VBD was considered a public health threat. In Greece, for example, *Ae. aegypti* was responsible for the spread of dengue, infecting more than 1 million people in Athens in 1928/9, with more than 1500 fatalities, while in Greece, Italy and Spain malaria affected millions of people every year until effective control became available. Since the late 1960s, these diseases have been brought under control. Sporadic small outbreaks are still reported, however, usually caused by cases imported from abroad.

The recent (re-)emergence of invasive mosquitoes with vector potential, however, gives reason to re-evaluate the VBD threat in the WHO European Region. Several mosquito species have become notorious for their successful invasion and establishment in the Region. Others are regular invaders but have not yet become established. Finally, there are reports of mosquito species exotic to the Region which are occasionally observed, usually as incidental cases (Chastel, 2009; Schaffner & Mathis, 2014).

Table 1. Invasive mosquito species in the WHO European Region [a]

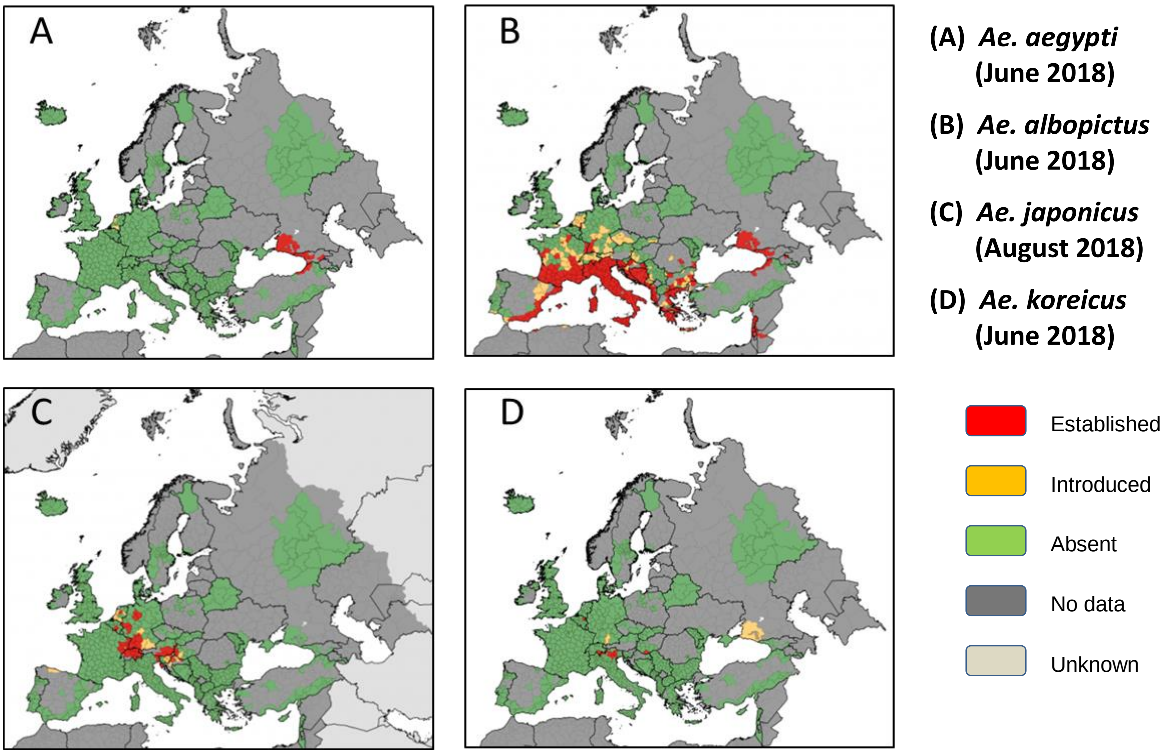
Species	Regional geographic distribution
Ae. aegypti	Canary Islands (Spain), Georgia, Madeira (Portugal), Black Sea coast of Russian Federation, north-east Turkey
Ae. albopictus	Albania, Armenia, Bosnia and Herzegovina, Bulgaria, Croatia, Former Yugoslav Republic of Macedonia, France, Georgia, Germany, Gibraltar (United Kingdom), Greece, Israel, Italy, Malta, Monaco, Montenegro, Romania, south of Russian Federation, San Marino, Serbia, Slovenia, Spain, Switzerland, north-east Turkey
Ae. japonicus	Austria, Belgium, Croatia, France, Germany, Hungary, Italy, Liechtenstein, Netherlands, Slovenia, Switzerland
Ae. koreicus	Belgium, Germany, Hungary, Italy, Russian Federation, Switzerland
Cx. tritaeniorhynchus	Greece

[a] See Medlock et al., 2015; Ganushkina et al., 2016; and ECDC, 2018.

2.1 Invasive mosquito species

Aedes aegypti. This species has its origin in tropical Africa. Of all mosquito species, *Ae. aegypti* is the most anthropophilic, feeding primarily on humans and closely associated with human habitation, where it lays its eggs in human-made water containers in and outside homes. The species invaded the Americas in the 17th century, following in the wake of the slave trade. Since then, it has spread all over the tropical and subtropical world and is now truly cosmopolitan. It is the main vector of yellow fever, dengue, chikungunya and Zika virus. Temperature appears to be the most important factor restricting distribution of *Ae. aegypti*, with a minimum average threshold temperature of 20 ºC. In the WHO European Region, *Ae. aegypti* is currently present along the Black Sea coasts in the south of the Russian Federation, Georgia, and north-east Turkey (Schaffner & Mathis, 2014; Akiner et al., 2016), as well as on Madeira (Portugal) and the Canary Islands (Spain). *Ae. aegypti* can survive in a dormant egg stage for several months, a trait that has allowed rapid transport across the globe. Recently, the species was found in the Netherlands, far outside its natural area of distribution; it was eliminated using insecticidal fogging and larval control with *Bacillus thuringiensis israelensis* (Bti), but was subsequently found again, in 2017 and 2018.[1] Establishment of this species, however, was not anticipated in this temperate country (Brown et al., 2011).

Fig. 2. Distribution of invasive mosquito species in the WHO European Region



Source: ECDC, 2018

[1] According to the Netherlands Food and Consumer Product Safety Authority (NVWA).

Aedes albopictus. This species, commonly known as the Asian tiger mosquito, was first described as exotic in the United States of America in 1986 (Hawley et al., 1987). It was discovered in Albania in 1979 and in Italy in 1990 (Dalla Pozza & Majori, 1992). The species has since spread into most southern European countries, where it has become established. Countries in the WHO European Region where *Ae. albopictus* is found are listed in Table 1; these include Albania, Armenia, Bosnia and Herzegovina, Bulgaria, Croatia, the Former Yugoslav Republic of Macedonia, France, Georgia, Germany, Gibraltar (United Kingdom), Greece, Israel, Italy, Malta, Monaco, Montenegro, Romania, the southern part of the Russian Federation, San Marino, Serbia, Slovenia, Spain, Switzerland and north-east Turkey (Medlock et al., 2015; ECDC, 2018b). Data from central Asian countries are scarce. In its native region, *Ae. albopictus* is a vector of dengue virus. The species became well known when it was identified as the principal vector of chikungunya virus in Réunion (France) in 2006; it subsequently spread to India and northern Italy. Although the native habitat of *Ae. albopictus* is tropical South-East Asia, the species has adapted well to the Mediterranean climate of southern Europe, including those areas with relatively cold winters. The species has recently become established in southern Germany, and findings are frequently reported from Belgium and the Netherlands (Scholte et al., 2012; Walther et al., 2017).

A special risk associated with *Ae. albopictus* is accidental import with ornamental plants (e.g. lucky bamboo) from East Asia (Scholte et al., 2008). The problem has been reported from the Netherlands, in particular, where imports have occurred every year since the first report in 2005. There is no evidence as yet that this type of import has led to population establishment.

Aedes japonicus. This species originates from Japan. It has been reported as established with small-scale focal distributions in the countries listed in Table 1; these include Austria, Belgium, Germany and the Netherlands (Medlock et al., 2015). In Switzerland, by contrast, it has become widespread in recent years. Introduction is most likely due to the trade in used tyres, as is also believed to be the case for *Ae. albopictus*. The species is considered a bridge vector for West Nile virus, and has potential as a vector of chikungunya and dengue (Schaffner et al., 2013).

Aedes koreicus. Like *Ae. japonicus*, this species originates from eastern Asia, including the Russian Federation, China and the Korean Peninsula. It is assumed to be a vector of arboviruses and filariasis. In the WHO European Region, *Ae. koreicus* was first reported from Belgium in 2008, and subsequently from Italy, in 2011, and southern Switzerland (Suter et al., 2015). Recently, it has also been recorded in Hungary and Germany (Kurucz et al., 2016; Werner et al., 2016).

Aedes atropalpus. Frequent introductions of *Ae. atropalpus* have been recorded (Schaffner et al., 2013). The species originates from North America and is most likely introduced through the trade in used tyres, after it has laid its eggs in water inside the tyres. Not much is known about its vector status (Turell et al., 2001). To date, the species has not become established in Europe, but the relative frequency of sightings in the summer suggests that it could eventually become established unless there is effective surveillance and control.

Aedes triseriatus. Like *Ae. atropalpus*, this species originates from North America. It actively bites humans, and in North America is a vector of West Nile virus, La Crosse virus and a range of other arboviruses. Despite the fact that sporadic introductions have not been rapidly cleared, the species has not become established in Europe.

Culex tritaeniorhynchus. This species originates from Asia, with additional records from the Mediterranean and the eastern parts of the WHO European Region. It has been recorded from

Turkmenistan, the Russian Federation and Turkey. The species was formerly absent from the western part of the WHO European Region, although records exist from Albania (Patsoula et al., 2017). In recent years it has frequently been observed in Greece (Patsoula et al., 2017), where it appears to have become established. In its native region (China, Japan, South-East Asia), *Cx. tritaeniorhynchus* is a vector of Japanese encephalitis, a serious and sometimes fatal arboviral disease.

There is a paucity of information on the invasion of exotic mosquito vectors in the eastern parts of the WHO European Region. While some information is available from the southern part of the Russian Federation, the countries of central Asia have not recorded the presence of new mosquito species in their region. This lack of information does not signify that invasive species are absent from these countries.

2.2 Native mosquito species expanding their distribution range and/or shifting ecological characteristics

Several mosquito species native to the WHO European Region have been observed to change their habitat, their natural geographical distribution and/or their seasonal phenology. Some of these species are aggressive biters and can act as disease vectors. The most salient examples of such species are listed below.

Anopheles hyrcanus. Although a native species of the eastern and southern parts of the WHO European Region (the southern part of the Russian Federation, Turkey, Greece, Balkans, southern France), *An. hyrcanus* has now been found further north – in Poland and Germany, for example, where it is reported to be a vector of the Tahyna virus (Hubalek et al., 2014). The species can act as a (secondary) vector of malaria (Linard et al., 2009), and it was recently reported as a putative vector of a flavivirus in Hungary (Zana et al., 2017).

Anopheles plumbeus. This anopheline species occurs throughout the Region. However, in recent years it appears to have adapted its habitat and is becoming a nuisance species. *An. plumbeus* can act as an effective vector of *Plasmodium* spp.; the combination of geographical shifts, increase in mosquito population density (including in urban areas), aggressive biting of humans and competent malaria vector makes it a species that merits close observation.

2.3 Mosquito species widely present and their role as vectors of pathogens

Culex pipiens pipiens. This species is possibly the most cosmopolitan of the WHO European Region. It has adapted to many different habitats, from the tundra in the north to the shores of the Mediterranean in Israel and southern Europe. It is the principal vector of West Nile virus in southern and south-eastern Europe (Sambri et al., 2013) and has been demonstrated to be a good vector of this virus in other areas of Europe (Fros et al., 2015; Vogels et al., 2017).

Aedes vexans. This species can occasionally explode in high numbers as a result of synchronized emergence. In such cases it is a great nuisance to the local population. In Africa *Ae. vexans* is considered to be an important vector of Rift Valley virus. Recent studies in North America revealed that *Ae. vexans* is capable of transmitting Zika virus (Gendernalik et al., 2017; O'Donnell et al., 2017).

3. Surveillance protocols

Prevention of (re-)introduction and control of mosquito vectors depends critically on surveillance activities. Effective planning, implementation and evaluation of vector control strategies and operations require data on the abundance, geographical distribution and seasonal dynamics of mosquito vectors, together with data on locally transmitted disease cases and an assessment of risks.

3.1 Entomological surveillance

Detailed guidelines on the surveillance of invasive and native mosquitoes in Europe are available from the European Centre for Disease Prevention and Control (ECDC) (ECDC, 2012; 2014). The current manual aims to build on the ECDC guidelines in order to provide countries with practical guidance on surveillance-based strategies and operations for prevention and control of mosquito vectors.

The ECDC guidelines identify three scenarios for invasive mosquitoes and two scenarios for native mosquitoes. For the purposes of this manual, which covers all potential mosquito vectors, both invasive and native, four scenarios are identified, as indicated in Table 2.

Table 2. Description of the four scenarios, with objectives and locations for surveillance

Item	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Description	Vector species not established	Vector species locally established	Vector species widely established, or native	Locally transmitted disease cases
Surveillance objectives	Detection of introduction and establishment at points of entry	Assessment and mapping of establishment and spread	Assessment and mapping of seasonal abundance	Assessment and mapping of seasonal abundance; pathogen screening of vectors
Surveillance locations	Ports and airports; storage sites for imported tyres; shelters/greenhouses for specific imported plants	Colonized area and surroundings	Colonized or native area (e.g. using sentinel sites)	Colonized or native area, with focus on disease case sites

These scenarios are described at the level of individual vector species. Thus, a country may be at Scenario 3 for *Ae. albopictus*, with populations of this species widely established, while simultaneously at Scenario 1 for other vector species, such as *Ae. aegypti*, which are at risk of being introduced at the country's points of entry.

3.1.1 The four scenarios

In **Scenario 1**, a vector species is not established in a country, but there is risk of introduction and establishment. This scenario assumes that surveys have been conducted in the country confirming the absence of the vector species. Surveillance activities would be concentrated at points of entry, which could include ports and airports, cross-border road and railway corridors, and storage sites for imported goods such as used tyres, to detect exotic mosquitoes upon their arrival (ECDC, 2012; WHO, 2016d).

In **Scenario 2**, an exotic vector species has been introduced and has been able to locally establish itself within a small area (less than 25 km²), and there is no evidence of spreading beyond that area. Surveillance activities would assess and map the area of establishment, and detect whether spread had occurred beyond this area. With current knowledge, in an area of less than 25 km² it is considered feasible to eradicate the invading mosquito species.

In **Scenario 3**, the vector species has become widely established (beyond an area of 25 km²) or is native; it is therefore not considered feasible to eradicate the vector. Surveillance activities would aim to assess the abundance, distribution and seasonal patterns of this species. While there is no evidence of local transmission of mosquito-borne diseases in this scenario, occasional or frequent reports of imported disease cases could increase the need for preparedness, with intensified surveillance of vector mosquitoes.

In **Scenario 4**, there is evidence of locally transmitted, mosquito-borne disease cases. This scenario implies the presence of vector mosquitoes in or around the contact points of confirmed disease cases.

3.1.2 Mosquito collection methods

Methods are available for sampling mosquito eggs, larvae, pupae and adults. The method chosen must be in accordance with the objectives of the surveillance and with the relevant scenario; it should also take into account the life stage to be sampled and the advantages and disadvantages of each method (Table 3).

Table 3. Overview of the main mosquito collection methods [a]

Collection method	Life stage	Advantage	Disadvantage	Objective [b]
Ovitrap	Eggs	Simple	Variable efficiency	1,2,3
Dipper sampling	Larvae, pupae	Direct result	Some habitats missed	2,4
Gravid trap	Ovipositing females	Relatively simple	Not very efficient	1,2,3,7,8
Human landing collection	Host-seeking females	Direct result	Laborious; ethical issues	2,5
BG-Sentinel	Adults	Efficient for specific species	Cost	1,2,3,8
Mosquito Magnet; CDC trap	Adults	Moderately efficient	Cost	1,2,3,8
Aspirator	Adults	Direct result	Laborious; inefficient	2,6,8

[a] See ECDC guidelines for further details (ECDC, 2012; 2014). Some methods only apply to mosquitoes with a certain biology.

[b] Objectives of surveillance indicated as:

(1) detect presence/absence
(2) assess population density
(3) assess seasonality
(4) determine habitat preference
(5) determine biting behaviour
(6) determine resting behaviour
(7) determine host preference
(8) detect pathogen infection.

The eggs of container-breeding aedine mosquitoes are sampled using **ovitraps**, which are containers of convenient size that are placed in the field to collect mosquito eggs. The average number of eggs per trap per day is a function of the number of females present and their oviposition activity. The efficiency of ovitraps depends to a large extent on the number of other oviposition sites available to female mosquitoes and the attractiveness of the trap itself. Ovitraps can be made more attractive to gravid females by dark colouring and the addition of attractive hay infusions and an oviposition surface on which female mosquitoes can deposit their eggs (e.g. a cardboard strip or polystyrene insert). Ovitraps must be routinely serviced and maintained so that they do not become additional breeding sites.

Gravid traps are designed to collect egg-laying females (*Aedes* spp., *Culex* spp.) that have taken at least one blood meal and are possibly infected; they are useful for monitoring pathogen circulation (ECDC, 2012). Recent experience from the European Region suggests that gravid traps are also effective for detecting the introduction of *Ae. albopictus* (E. Falcuta, Cantacuzino Institute, Bucharest, Romania, personal communication, 2018). In addition, gravid traps can be used for detection of low densities of *Ae. albopictus*, *Ae. aegypti* and possibly other species.

Larval sampling is a core element of mosquito surveillance that provides information on the location, species and population densities of native or introduced mosquitoes. Mosquito larvae and pupae are commonly collected with a white dipper sampler, which allows the number caught per dipper sample to be counted. Several techniques have been developed for optimal use of the dipper, depending on water depth and targeted mosquito species. Small water-filled containers can be emptied into a white container that allows mosquito larvae to be easily spotted; or they can be sieved. Cryptic breeding sites such as water-filled tree holes can be sampled with a pipette.

Traditionally, a number of indices have been employed for surveillance of the container-breeding vector *Ae. aegypti*; these are used for house-to-house sampling in the context of programmes to control yellow fever or dengue. These indices include the *House index* (percentage of houses with larvae or pupae present); the *Container index* (percentage of water containers infested with larvae/pupae); and the *Breteau index* (the number of positive containers per 100 houses inspected). The main limitation of these indices is their poor predictive value for adult vector density or transmission risk; they are therefore of rather limited usefulness in the Region. The productivity of water containers is variable, with some types of container producing many adult *Aedes* mosquitoes, others few. More recently, the *Pupal index* (number of pupae per house divided by the number of persons per house) has been promoted as a superior alternative to the more traditional indices in measuring risk of dengue transmission (Focks & Barrera, 2007; Scott & Morrison, 2010); it is more demanding as a routine monitoring activity, however, because it requires precise counting of the pupal stage.

A number of methods are available for collection of adult mosquitoes. The simplest is by the direct collection of resting mosquitoes using a manual or motorized **aspirator**. The manual aspirator is also used for **human landing collection**, by exposing an arm or leg and monitoring host-seeking mosquitoes. There are ethical considerations concerning this method, particularly where there is a risk of circulating pathogens for which no vaccination or medication exists. For this reason, human landing catches are not generally recommended. In some settings, it may be useful to use sweep-net sampling of vegetation to collect resting adult mosquitoes.

A more ethical way of collecting adult mosquitoes is **trapping**. There are a number of commercially available traps, using light, carbon dioxide (CO_2) and/or lures to attract mosquitoes. The BG-Sentinel trap is particularly efficient in collecting *Ae. albopictus* or *Ae.*

aegypti, as a chemical lure is used to attract them; this can be seen as the modern alternative to human landing catches. The Mosquito Magnet trap and CDC traps use CO_2 to attract host-seeking mosquitoes.

Gravid traps are designed to collect egg-laying females (*Aedes* spp., *Culex* spp.) that have taken at least one blood meal and are possibly infected; they are useful for monitoring pathogen circulation (ECDC, 2012). Recent experience from the European Region suggests that gravid traps are also effective for detecting the introduction of *Ae. albopictus* (E. Falcuta, Cantacuzino Institute, Bucharest, Romania, personal communication, 2018). In addition, gravid traps can be used for detection of low densities of *Ae. albopictus*, *Ae. aegypti* and possibly other species. Moreover, these traps are useful for arboviral screening of trapped individuals, as gravid females have taken at least one blood meal. Gravid traps can sometimes also be used for detection of established mosquito populations, where breeding sites are difficult to detect.

Most mosquito collection methods are suitable for use in all four scenarios (Table 4). In Scenario 1, ovitraps and larval surveys, as well as adult traps, are useful at ports of entry to detect exotic mosquito species at the point of introduction. The same methods are useful in Scenario 2 to detect newly invading mosquitoes. In Scenarios 3 and 4, where mosquito vectors have become widespread or abundant and where there are circulating human pathogens, additional methods, such as aspirators or gravid traps, are useful; these can be used to collect resting and ovipositing mosquito samples, which can subsequently be used for pathogen screening.

Table 4. Use of mosquito surveillance methods in each scenario

Item	**Scenario 1** *Vector not established*	**Scenario 2** *Vector locally established*	**Scenario 3** *Vector established or native*	**Scenario 4** *Local disease transmission*
Larval/pupal survey	✓	✓	✓	✓
Ovitraps	✓	✓	✓	✓
Gravid traps	✓	✓	✓	✓
BG-Sentinel, Mosquito Magnet	✓	✓	✓	✓
Aspirators	–	–	✓	✓
Human landing catch	–	–	✓	–

3.1.3 Vector parameters

The most common use of entomological surveillance is to measure population abundance. The objective may be to confirm presence or absence of invasive mosquitoes; to monitor the density or seasonal dynamics of established populations of vector mosquitoes; or to evaluate the effectiveness of vector control interventions. Methods recommended for measuring population abundance are dipper sampling of larvae/pupae, adult trapping and human landing collection, provided that the ethical issues involved in the latter method are fully taken into account (ECDC, 2014). The collection of adult mosquitoes and eggs provides a relative measure of density, and their catches are influenced by a number of environmental and weather factors.

In addition to routine surveillance of population abundance, special studies are required to elucidate the productivity of breeding habitats, biting behaviour, resting behaviour, host preference and insecticide susceptibility status of vector mosquitoes. Planning and prioritization of such studies require close interactions between the operational programme and researchers.

Productivity surveys aim to identify the main breeding sites of container-breeding *Aedes* mosquitoes; this information is needed to guide decisions on methods and priorities for surveillance and control activities. Container productivity refers to the relative importance of each type of vector breeding container for producing adult mosquitoes (WHO, 2011b).

Circadian biting activity is studied at fixed intervals throughout the day and night to find out the times humans are most at risk of being bitten and possibly infected by a pathogen.

Host feeding and host preference can be studied by collection of blood-fed females and laboratory analysis of blood meals; numbers of mosquitoes collected with animal-baited traps can also be compared with human landing catches. A high human blood index indicates that the mosquito is highly anthropophilic and thus, if competent for a specific pathogen, could be an efficient vector for that pathogen. A species feeding on a range of hosts would generally be a less efficient vector of human pathogens, but it could be important for its role as a “bridge vector”, by circulating zoonotic pathogens between animal hosts and humans.

Another important vector parameter is the pathogen infection rate (ECDC, 2012). This is used to determine whether human pathogens are circulating and, in case of an outbreak, to estimate the rate of transmission. Pathogen screening in mosquito vectors contributes to disease surveillance, particularly for diseases with a large proportion of asymptomatic infections that remain unreported to the health system; in such cases, the circulating pathogen may be detected through screening of mosquito specimens. Pathogen screening is also used to study the role of the mosquito species as vector of the human pathogens. Trapped female mosquitoes are taken to the laboratory soon after collection for identification and preparation for laboratory screening to detect and identify pathogens. Limitations of pathogen screening are the large numbers of mosquito specimens needed and the high costs of analysis. Moreover, negative results do not prove that the pathogen is absent.

3.1.4 Organizational aspects

Several considerations should be taken into account when establishing an entomological surveillance system for mosquito vectors. These include identification of a coordinating unit and partners in surveillance; and identification of training needs on issues such as field data collection, mosquito identification, pathogen screening, data management, mapping, data feedback and data utilization. In addition, countries need to establish the frequency of field data collection on the basis of available resources.

3.2 Epidemiological surveillance

Epidemiological surveillance is collection of data on disease status within a human population. Such surveillance is essential for early detection of sporadic cases or outbreaks; this allows a prompt response action to be triggered, in which health care providers are alerted, resources allocated, and the community mobilized.

Epidemiological data are also needed to conduct risk assessment, to monitor geographical distribution and temporal changes in disease cases, and to evaluate the effectiveness of interventions. Such data may be obtained from various sources, including clinical reporting of possible or probable cases, laboratory reporting of confirmed cases or serotypes, active on-site surveillance, case investigation, and special studies.

Passive surveillance relies on notified disease cases reported by health care providers at primary care or hospital levels, and on reports of laboratory-confirmed cases. Passive case detection, which is the commonest type of epidemiological data, may suffer from irregular or late reporting. Moreover, cases may be missed because not all infected persons report to health facilities, or because capacity for diagnosis and laboratory testing is inadequate.

Active surveillance comprises various activities intended to maximize the proportion of cases that are reported. This kind of surveillance involves active linkage between health authorities and health facilities and laboratories, so that data are requested and reporting is encouraged. It can also involve on-site surveillance targeted at symptoms or pathogens in high-risk populations. When cases are sporadic, case investigation is essential to establish, by looking at a person's travel history, whether a particular case was imported or locally acquired, and hence whether the pathogen is actively circulating or not.

The surveillance system should be linked to a national health information system, to enable efficient data sharing. In this way, data will be made available on a regular basis at district level to improve feedback for decentralized decision-making on resource allocation and response action.

The strength of epidemiological surveillance depends to a large extent on the training and capacity of clinicians at primary care level to diagnose and promptly refer and report possible mosquito-borne disease cases. Furthermore, the community should be made aware, through communication strategies, of the signs and symptoms of emerging diseases, so that infected individuals report for diagnosis and medical care within a certain number of hours following the onset of illness. The time within which it is necessary to report for diagnosis depends on the disease in question.

3.3 Risk assessment

Risk assessment is an instrument that uses surveillance data, together with other available information sources, to identify threats and to assign a level of urgency to a situation or geographical area. Risk assessment is a crucial element in decision-making on policy, resource allocation, capacity-building and interventions. Technical guidance on risk assessment with respect to mosquito-borne diseases is discussed in separate documents (ECDC, 2012; 2014).

Within the scope of this manual, the relevant threat is the potential burden of emerging mosquito-borne diseases in the WHO European Region and, indirectly, the implications that these emerging diseases could have for travel, trade, investment, workforce output, school attendance and health system costs.

The risk is a product of importation of disease cases or infectious animal hosts (called "vulnerability"), and the risk of outbreaks (called "receptivity"), which depends on the presence of mosquito vectors and on the level of immunity in the human population. The global surge and expansion of arboviral diseases, together with the steady rise in global passenger travel, have substantially increased the importation risk of disease cases both into the Region and between countries within the Region. Risk assessment applies to each of the four scenarios described in Section 3.1.1 above.

The introduction of exotic vectors at points of entry is not in itself a direct treat, except in the unlikely event that a vector specimen is infected and successfully transmits the pathogen upon arrival. Rather, the risk is that the introduced vector, once established, will increase local receptivity to emerging disease.

Where mosquito vectors have established themselves or are native species, risk mapping should be carried out to stratify geographical areas according to the level of disease risk, based on entomological, environmental and socioeconomic parameters. For example, areas that have abundant *Ae. aegypti* or *Ae. albopictus* populations and dense human populations are highly receptive to arboviral diseases such as dengue and chikungunya. In such situations, a single imported case could cause a local outbreak. The role of invasive and native mosquito species as vectors of disease pathogens requires further investigation. Also, it is important to know whether wild or domestic animals are included locally in the transmission cycle.

Where there are locally transmitted disease cases, the location of sporadic cases or outbreaks becomes the leading factor in risk assessment, providing the basis for intensified surveillance and emergency response action. The risk of epidemics also depends on the ability of health care providers to detect cases early, community awareness of the need to seek medical attention, and capacity for rapid and coordinated response action.

4. State-of-the-art methods for control of mosquito vectors

Historical examples show that vector control against *Ae. aegypti*-borne diseases has been effective (Gubler, 2011).

A number of methods are available, and have been used by field programmes, for control of immature aquatic mosquito stages and adult mosquitoes; other methods aim to prevent mosquitoes by eliminating breeding sites through measures such as environmental management. A recent review document provides a comprehensive overview of the use of methods to control *Ae. aegypti* and *Ae. albopictus* (ECDC, 2017). Some methods aim to control vector mosquitoes by killing the immatures or adults; others aim to prevent the vector from breeding or from contact with human hosts. Some methods are best implemented by the community, while others depend on implementation by certified personnel and use of special equipment for insecticide application and other tasks.

Clearly, the immediate risks of mosquito-borne diseases in the WHO European Region are associated with *Ae. aegypti* and *Ae. albopictus*, as these species are implicated as vectors in recent outbreaks of dengue and chikungunya. For this reason, the emphasis in this chapter will be on methods to control container-breeding *Aedes* species (presented in Section 4.1). The invasive mosquito species *Ae. japonicus*, *Ae. koreicus* and *Ae. triseriatus* are covered in the same category (Table 5). Some of the methods discussed will also be applicable to other types of mosquito vector. In addition, Section 4.2 will discuss vector control methods for mosquito species with different breeding ecologies.

Table 5. Container-breeding *Aedes* vector species, their breeding habitats and potential diseases transmitted

Species	Habitats	Diseases (potential)[a]
Ae. aegypti	Artificial containers, drains, pits, tree holes, rock pools	CH, DE, YF, ZI
Ae. albopictus	Artificial containers, drains, pits, tree holes, rock pools	CH, DE, DI, ZI
Ae. japonicus	Artificial containers, drains, pits, tree holes, rock pools	*CH, DE, WN*
Ae. koreicus	Artificial containers, drains, tree holes, rock pools, tracks	*DI, JE*
Ae. triseriatus	Artificial containers, tree holes, rock pools	LC

[a] **CH** Chikungunya **JE** Japanese encephalitis **YF** Yellow fever
DE Dengue **LC** La Crosse encephalitis **ZI** Zika
DI Dirofilariasis **WN** West Nile fever

Normal font indicates proven vector.
Italic font indicates diseases for which the mosquito is a potential vector.

Source: ECDC, 2012; Medlock et al., 2015

4.1 Control methods against container-breeding *Aedes* vectors

Recent systematic reviews of the effectiveness of vector control methods against *Ae. aegypti* and *Ae. albopictus* in the context of dengue control have concluded that there is a paucity of reliable evidence: there are few rigorous studies available on the impact of vector control on the vector population or on dengue incidence, and there is a need for standardized and comparative studies (Erlanger et al., 2008; Bowman et al., 2016). As a result, we do not have a clear understanding of which of the currently available interventions actually work, nor of the conditions under which they work (Bowman et al., 2016). Nevertheless, the shortage of evidence does not mean that the available methods are ineffective.

The methods for which most evidence on their effectiveness is available are source reduction (but only as one element of an integrated strategy) and house screening. In addition, there is experience in the European Region of the use of insecticides to suppress or eliminate local *Aedes* populations (see Section 5.2.5, Box 1). These methods include larviciding and targeted residual spraying. Emergency space spraying is also added to this section because it is still considered a useful tool in emergency situations (outbreaks or epidemics) for *Aedes*-borne viruses, even though evidence on its effectiveness is largely lacking (Table 6). Space spraying is not recommended for malaria prevention or control.

Table 6. Use of control methods against container-breeding *Aedes* vectors in each scenario

Item	**Scenario 1** *Vector not established*	**Scenario 2** *Vector locally established*	**Scenario 3** *Vector established or native*	**Scenario 4** *Local disease transmission*
Source reduction	✓	✓	✓	✓
Larviciding	✓	✓	✓	✓
House screening	–	–	✓	✓
Targeted residual spraying	✓	✓	–	–
Emergency space spraying	–	–	–	✓

4.1.1 Source reduction

Source reduction is defined as the modification or elimination of aquatic habitats to reduce mosquito breeding (Kitron & Spielman, 1989); its aim is to control mosquitoes at their source of breeding. In their aquatic immature stages, mosquitoes are arguably at their most vulnerable; at this stage, they can easily be controlled, provided that most breeding sites can be covered by the control effort. The term “container-breeding”, applied to *Aedes* vectors, has connotations of breeding in small water-filled vessels, which can be human-made or natural. Unlike many other mosquito species, these *Aedes* species do not breed in larger stagnant water bodies such as ponds or flooded fields.

Effectiveness

Source reduction prevents *Aedes* mosquito larvae from developing in treated containers. The question is whether an adequate proportion of breeding sites utilized by ovipositing females can be covered by source reduction, and whether this coverage can be achieved during times of peak mosquito breeding.

Source reduction has been the most commonly studied intervention for dengue control (Bowman et al., 2016). However, in most of the available studies, source reduction was conducted in conjunction with one or more other methods, such as larviciding, space spraying and use of biological control agents. Hence, in most cases it is impossible to disentangle the effect that is attributable to source reduction. One study from Cuba demonstrated convincing evidence that source reduction, implemented through community groups, was effective against dengue transmission (Toledo et al., 2011). More recently, there was evidence that community mobilization for dengue vector control in Mexico and Nicaragua had an impact on dengue incidence and vector indices (Andersson et al., 2015; Arosteguí et al., 2017). Several other studies indicated the impact of community-based source reduction on the vector or on vector indices (Erlanger et al., 2008; Bowman et al., 2016). Even so, for the most part it remains unclear to what degree the habitats of container-breeding *Aedes* vectors must be reduced (i.e. what level of coverage the source reduction intervention needs to achieve) to substantially reduce transmission, or transmission risk, of arboviral diseases such as dengue or chikungunya (WHO, 2012c).

Source reduction methods

Container-breeding *Aedes* vectors can utilize a wide range of container types for their offspring (Table 7). Flower vases are commonly used because of the nutrients they hold and the continuous presence of water. Likewise, bird baths and dishes beneath potted plants represent common breeding sites. Such sites are always in the direct vicinity of human hosts. Replacing the water in these containers will kill any vector larvae or pupae, but not the eggs, which are deposited at the edge of, or above, the water surface and need to be actively removed by scrubbing; otherwise, they will emerge in the newly replaced water.

Table 7. Commonly preferred breeding sites of container-breeding *Aedes* vectors, and possible interventions for source reduction

Breeding habitats	Source reduction interventions
Flower vases, plant pot dishes, bird baths	Remove if not needed; regularly clean and scrub
Solid waste (plastic rubbish, tins, containers)	Clean-up campaign; recycle; dispose
Bulk waste (household items too large for rubbish collection)	Municipal services; clean-up campaign
Used tyres, left outdoors	Recycle or dispose; protect from rainwater
Water storage basins, rainwater barrels/butts	Remove; regularly clean and scrub; cover
Unused swimming pools	Keep filled with chlorinated water; drain
Drains, gutters	Maintain; clean; remove
Tree holes	Fill with cement, stones
Rock pools	Fill with stones, soil

Solid waste, such as plastic containers or tins, and any rubbish that can accumulate rainwater are potential sites for container-breeding *Aedes* vectors. This type of waste is common in urban and suburban settings where there are high densities of human hosts, both in the public domain (e.g. along roadsides, ditches, parks, schoolyards) and on private property (e.g. backyards, construction sites, deserted properties).

Bulk waste comprises large items, including discarded television sets, refrigerators, baths, buckets and vehicle parts, that are not picked up by regular waste collection services. Bulk waste is a common feature in many peri-urban environments and can create some highly productive breeding sites for *Aedes* vectors. Clean-up of bulk waste typically involves municipal services with the participation of local residents. As an interim measure before clean-up is organized, all items that collect water should be turned upside down for an immediate effect on the immature mosquito stages.

Used vehicle tyres left outdoors are notorious breeding sites for *Aedes* vectors because the water accumulated inside the tyres can remain for long periods. Discarded tyres should be collected, recycled or otherwise disposed of. Furthermore, used tyres imported from abroad may contain diapausing eggs of exotic *Aedes* vectors which could hatch inside the tyres upon contact with water. For this reason, used tyres that are imported from abroad are a particular risk factor for introduction and establishment of invasive mosquitoes. They should therefore be kept in shelters until their final use or retreading.

Water storage basins and rainwater barrels (butts) are examples of containers where the water is collected for a specific use. Such containers can produce large numbers of *Aedes* vectors and should be removed, provided with a sealed cover, or regularly emptied and scrubbed. Unused swimming pools accumulate rainwater and inadvertently contribute to *Aedes* populations. Possible interventions to avoid *Aedes* breeding are to keep swimming pools in use, to drain regularly, or to apply larvicides regularly (see 4.1.2).

Blocked drains and gutters can cause water stagnation, resulting in favourable breeding sites for container-breeding *Aedes* vectors. Regular cleaning and maintenance by householders or those responsible for maintaining public buildings can avert this problem. Moreover, in the case of new constructions, improved building standards can remove most of these risks.

Natural habitats of container-breeding *Aedes* vectors include tree holes and rock pools. In the vicinity of houses or public places, it may be desirable to remove these breeding places, by filling them with cement, stones or soil, or possibly by draining.

When and where to use

Source reduction may be considered the primary method of controlling container-breeding *Aedes* vectors. It constitutes an important method in all four risk scenarios, from preventing introduction at ports of entry to conditions where there are locally transmitted disease cases (Table 6). Depending on the rainfall pattern and on the rate at which new breeding containers emerge, source reduction should be repeated regularly, at weekly or fortnightly intervals, during the mosquito breeding season.

Ae. aegypti and *Ae. albopictus* live in close association with humans, inhabiting houses, yards, schools, workplaces, cemeteries and parks. In such places, source reduction is often the most straightforward, safest and most acceptable method, and can be implemented by anyone. It may, however, be more challenging during the rainy season, when vector breeding in standing water may be much more prevalent.

The flight range and host feeding behaviour of vector species have implications for the area where source reduction is necessary. *Ae. aegypti* and *Ae. albopictus* have a short flight range, with a maximum of 200–300 m (ECDC, 2012), which implies that breeding sites further away from human habitation have lower priority for control. Most *Aedes* vectors fly minimal distances and remain in or around the house where human hosts are present. *Ae. aegypti* feeds almost exclusively on human hosts, while *Ae. albopictus* and *Ae. japonicus* feed on other mammals and (to a lesser degree) birds as well. Consequently, *Ae. albopictus* and *Ae. japonicus* may breed further away from human habitation. Depending on the programme objectives, source reduction in these isolated locations could be considered as well as in and around homes.

Some breeding habitats that cannot easily be removed, filled or drained should be treated with insecticides (see 4.1.2). This indicates that source reduction and larviciding are complementary methods.

Productivity surveys

Not all water containers will be equally productive of *Aedes* vectors. Oviposition preference by female *Aedes* mosquitoes will vary between container types, and biotic and abiotic conditions inside each container will influence preference. Consequently, larval development may be limited in some containers, while other containers produce large numbers of mosquitoes.

Studies have indicated that productivity of water containers can be measured by counting the number of pupae, as proxy for the emerging adult mosquitoes (Focks et al., 2006). Productivity surveys are conducted by counting the number of pupae in each container type and then ranking the container types according to their absolute productivity per hectare (0.01 km^2). The more productive types of breeding site can then be deliberately targeted by a programme, while less productive sites are omitted from control action. In this way, programmes can make more efficient use of their surveillance and control resources.

Productivity surveys are intended not as a routine activity but as a special study to identify the types of productive habitat in a given geographical area. An operational guide is available for assessing the productivity of *Aedes* breeding sites. The guide presents standard operating procedures for conducting pupal productivity surveys (WHO, 2011b).

Roles

Source reduction activities do not generally require skilled workers or special equipment, and can be performed by lay (nonprofessional) people. Source reduction in and around houses and on private property depends critically on the active participation of residents within a community, so advocacy and health education are required. Source reduction at schools, hotels and workplaces requires the involvement of the education sector and the private sector. Municipalities and their sanitation and waste collection services have an important role in maintaining cleanliness in public places and along streets; this includes occasional collection and disposal of bulk waste. Moreover, the environment ministry, municipalities and nongovernmental organizations (NGOs) have a role in organizing clean-up campaigns and in establishing or expanding systems for recycling items such as plastics, tins, glass and tyres. Combining control of disease vectors with mosquito nuisance control may result in greater motivation and compliance among those involved.

Regulations

Several persuasive measures could be taken to promote source reduction. Possible measures include fines for littering or dumping of bulk waste (removal of rubbish and bulk waste has benefits beyond vector control because it also reduces breeding of houseflies, rodents and other pests). Countries could promote recycling of plastic or tin waste through a recycling programme and an awareness-raising campaign, while regulations on imported used tyres could help to reduce the risk of introducing exotic mosquitoes.

A common constraint in source reduction is restricted access to private property (such as backyards), which can provide environments where container-breeding *Aedes* vectors breed. Special regulations could allow inspectors to gain access to private property under certain circumstances – for example, during emergencies when sporadic cases have been detected; however, there are clearly ethical issues concerning such regulations.

Monitoring and evaluation

Implementation of source reduction can be monitored through several input and process indicators, such as staff inputs, number of clean-up campaigns and level of participation in them, and level of participation among municipal services and other agencies. The output of source reduction can be evaluated by using available larval indices, particularly the Breteau index, which measures the number of positive containers per 100 houses. It is important to monitor these indices consistently – that is, by routinely sampling the same houses, or all houses (to address the issue of differences between them). Moreover, indicators for adult mosquito density (e.g. trap catches) are essential for evaluation of the impact of source reduction on *Aedes* populations.

4.1.2 Larviciding

Larviciding is the application of appropriate bacterial or chemical insecticides to aquatic mosquito breeding sites. The objective of larviciding is to eliminate vector larvae from aquatic breeding habitats in order to reduce the vector population. As the residual activity of larviciding is temporary, the intervention should be conducted at regular intervals.

Effectiveness

With the use of appropriate products, equipment and methods, larviciding eliminates larvae from treated water containers. However, there is limited evidence on the effectiveness of larviciding in reducing pathogen transmission. One reason for this is that larviciding has rarely been studied as an intervention on its own; evidence on its effectiveness comes from studies in which it was used in combination with source reduction and/or space spraying (Erlanger et al., 2008; Bowman et al., 2016). Indeed, when source reduction is the primary method of control, larviciding should always have a supplementary role in controlling populations of container-breeding *Aedes* vectors, as a means of spraying breeding sites that cannot be removed or that have a specific function (e.g. as water storage).

Selection of insecticides

Insecticide compounds and formulations that are currently recommended by WHO for larval control in water containers are indicated in Table 8; the list is periodically updated on WHO's website (WHO, 2018). The WHO-recommended larvicides have recently undergone an efficacy and risk assessment and are valid for use in public health when linked with WHO specifications for their quality control (WHO, 2018). Not all these compounds are currently available or authorized in the European Union (EU) market.

Broadly speaking, there are three categories of recommended insecticides for control of mosquito larvae: bacterial insecticides, insect growth regulators (IGRs) and synthetic chemical insecticides. In the past, synthetic chemical insecticides were the dominant category used for larviciding. More recently, bacterial insecticides, and to some extent IGRs, have become the preferred insecticide category for use against larvae of container-breeding *Aedes* vectors (Becker & Zgomba, 2007).

Bacterial insecticides. These insecticides are based on bacterial species that produce specific crystal proteins during sporulation. These proteins are toxic to mosquito larvae when ingested. Products based on *Bacillus thuringiensis israelensis*, known as Bti, are highly effective in mosquito control. Bti kills mosquito larvae but is not toxic to other insects; it is harmless to fish, birds, mammals and humans, provided that the product is handled and applied according to label instructions. Bti's safety and easy handling make it an attractive insecticide for use at municipality or community level, and it can safely be applied to containers within the peridomestic environment, in schoolyards and around workplaces. Bti produces four proteins that are toxic to mosquito larvae. This set of four toxins safeguards against the development of resistance in mosquito populations. A disadvantage of Bti is its relatively short residual activity in the field, especially when exposed to direct sunlight; repeated application is therefore required during periods of peak mosquito activity.

Table 8. Insecticide products for control of container-breeding mosquito larvae, as recommended by WHO

Product name	Active ingredient	Class
Abate 1 SG	Temephos	Organophosphate
Abate 500 EC	Temephos	Organophosphate
Actellic EC	Pirimiphos-methyl	Organophosphate
Device 25 WP	Diflubenzeron	Chitin synthesis inhibitor
Dimilin GR	Diflubenzeron	Chitin synthesis inhibitor
Du-Dim 2 DT	Diflubenzeron	Chitin synthesis inhibitor
Limitor-5 GR	Pyriproxyfen	Juvenile hormone mimic
Mosquiron 100 EC	Novaluron	Chitin synthesis inhibitor
Mozkill 120 SC	Spinosad	Spinosyn
Spinosad 0.5 GR	Spinosad (mixture spinosyn A + D)	Spinosyn
Spinosad 20.6% EC	Spinosad (mixture spinosyn A + D)	Spinosyn
Spinosad 25 Ext. Release GR	Spinosad (mixture spinosyn A + D)	Spinosyn
Spinosad 7.48% DT	Spinosad (mixture spinosyn A + D)	Spinosyn
Spinosad Monolayer DT	Spinosad (mixture spinosyn A + D)	Spinosyn
Sumilarv 0.5 G	Pyriproxyfen	Juvenile hormone mimic
Sumilarv 2 MR	Pyriproxyfen	Juvenile hormone mimic
Temeguard 50 EC	Temephos	Organophosphate
VectoBac GR	Bti strain AM 65-52 (Delta-endotoxin)	Bacterial
VectoBac WG	Bti strain AM 65-52 (Delta-endotoxin)	Bacterial
VectorMax FG	Bti AM 65-52 + B.sphaericus, ABTS-1743	Bacterial

Source: WHO, 2018

Another recommended bacterial insecticide is based on a mixture of Bti and *Lysinibacillus (Bacillus) sphaericus* (Lsph), which shows promising features for the control of container-breeding *Aedes* vectors. Lsph has a longer residual activity than Bti and produces one toxin composed of two proteins. Repeated application of Lsph on its own has been shown to lead to resistance in the mosquito population, but in the mixture of Bti and Lsph, this risk is reduced.

A new, related group of biorational insecticides includes Spinosad, which consists of two neurotoxins extracted during fermentation of the actinomycete bacterium *Saccharopolyspora* *spinosa* (Hertlein et al., 2010). Spinosad is not as specific as Bti, but it is non-toxic to vertebrates and has demonstrated a relatively long activity period when applied to vehicle tyres (Marina et al., 2012).

Insect growth regulators (IGRs). IGRs are a special group of insecticides that prevent the development of insect larvae and pupae into adults (juvenile hormone mimics) or that kill larvae when they moult (chitin synthesis inhibitors, or benzoylureas). IGRs are more specific than traditional chemical insecticides but less specific than bacterial insecticides, because they affect a range of insect groups, not just mosquitoes. Some IGRs have the advantage that they can persist considerably longer than Bti. IGRs present a low risk to human health. Some IGRs are currently available in the EU market; others are under review.

Chemical insecticides. Use of traditional chemical insecticides, such as the organophosphates temephos and pirimiphos-methyl, is less recommended for use in the peridomestic environments where container-breeding *Aedes* vectors occur. The acute toxicity and broad-spectrum effects of these chemicals can make them harmful to non-target organisms and toxic to humans; however, WHO-recommended products are assessed for their risk to human health, impact on non-target organisms and efficacy against the target vector. The lower cost of these products as compared to bacterial insecticides or IGRs could easily be outweighed by the increased precautionary measures required, in terms of training, personal protective equipment and exposure monitoring, and by the potential adverse effects of these chemicals on humans and ecosystems.

Where and when to use

Alongside source reduction, which is the primary method of controlling container-breeding *Aedes* vectors, larviciding is used as a supplementary method, to treat only those habitats that cannot be removed, filled or drained. Together with source reduction, larviciding is an important method in all four risk scenarios (Table 6): at ports of entry and in locally colonized areas to prevent or eliminate invasive mosquitoes, and in locations where widely established vectors present a risk of disease transmission.

Larviciding operations should be preceded by entomological surveys to find and map productive habitats that cannot be removed, filled or drained. These maps then form the basis for planning of control action. In the peridomestic environment, only safe products such as Bti should be used for larviciding. The optimal cycle of larviciding applications depends on the seasonality of *Aedes* vectors, the amount of rainfall, and the residual activity of the insecticide product (which, in turn, is linked to temperature and sunlight exposure). In hot, sunlit conditions, Bti may need to be applied at 2–3-week intervals.

Spray methods and equipment

Larviciding of aquatic habitats of container-breeding *Aedes* vectors is done by ground application. Because of the small volume of breeding containers, modest amounts of spray mix are needed during operations. For this reason, manual compression sprayers usually suffice. This spray equipment can easily be carried around by individuals or small teams, who should be flexible enough to implement source reduction wherever the situation demands.

Some bacterial insecticide and IGR products are available as granular formulations, which can be applied to breeding habitats by hand. Granules can be highly practicable for container-breeding *Aedes* vectors, as they can be added to flower vases or put into water barrels, for example.

Appropriate personal protective equipment must be worn, and personal hygiene observed, by spray workers handling and applying chemical larvicides (WHO, 2006b). Spray workers who routinely apply chemical insecticides should be regularly examined and submitted to a cholinesterase test (in case of exposure to organophosphates). When using chemical insecticides, care must be taken to avoid contamination of aquatic habitats containing non-target organisms.

Monitoring and evaluation

The inputs and process of implementation of larviciding can be monitored, with respect to standard operating procedures, through indicators such as staff time invested, surface area covered, amount of insecticide used, and frequency of operations. Monitoring should also include bioassay testing of insecticide susceptibility at sentinel sites, at least at annual intervals (see Section 7.6). The coverage and effect of an intervention can be evaluated by doing field efficacy tests through pre- and post-spray observations at selected sites. For more details on larviciding, refer to WHO's *Larval source management* (WHO, 2013a).

4.1.3 Screening of windows and doors

Container-breeding *Aedes* vectors commonly search for human blood meals inside houses, schools and workplaces. *Ae. aegypti* bites predominantly indoors, whereas *Ae. albopictus* bites mostly outdoors but can also adapt to the indoor environment (Dieng et al., 2010; Valerio et al., 2010). Keeping mosquitoes outdoors therefore protects people living indoors against possibly infective bites. Screening of windows and doors can provide an effective barrier to keep mosquito vectors out. Screening has the added advantage that it also keeps out other vectors, pests and nuisance insects.

Effectiveness

There have been a large number of studies conducted in the field of malaria control that consistently indicate that methods of house improvement aimed at reducing entry and resting of mosquito vectors substantially reduce the risk of contracting malaria (Tusting et al., 2015). In sub-Saharan Africa, it has been estimated that house improvement provides the same level of protection against night-time biting malaria vectors as insecticide-treated bed nets (Tusting et al., 2017).

In a meta-analysis of studies on dengue vector control, the evidence suggested that house screening was the most effective method of preventing dengue transmission, reducing the risk of contracting the disease by 22% (Bowman et al., 2016). In particular, strong evidence emerged from studies carried out in Australia and Taiwan (Ko et al., 1992; Murray-Smith et al., 1996; McBride et al., 1998).

When and where to use

House screening prevents entry of houseflies, nuisance mosquitoes and other pests, so it could, in principle, be beneficial in many different contexts. From a public health perspective, however, efforts to actively promote house screening in targeted communities would only be justified where there is an imminent or potential risk of mosquito-borne disease transmission in areas where the local vectors frequently bite indoors. Such a decision should be informed by surveillance data or special studies on indoor biting rates.

House screening is not an intervention that can quickly be rolled out; it takes considerable time to reach adequate levels of house screening "coverage" in communities. In view of this time factor, initiation of house screening interventions or campaigns can be recommended wherever *Ae. aegypti* or *Ae. albopictus* have become established.

House screening should not be limited to houses, apartments or workplaces. Schools and hospitals appear to be particularly high-risk sites for pathogen transmission by daytime-biting *Aedes* species, as there is a high density of human hosts, long periods of potential human exposure, and the relative vulnerability of schoolchildren and hospital patients to arboviral diseases and their complications. Consequently, schools and hospitals should be prioritized as initial targets for screening of windows and doors. Hotels are also a priority for screening, as there is a potential for imported cases (or asymptomatic pathogen carriers) among hotel guests who arrive from abroad.

Methods of screening

The screening material should be a fine-mesh wire gauze that does not allow mosquito passage and does not easily corrode or deteriorate over time. Aluminium screening can provide an affordable and durable option. Window screening is achieved by fitting to existing window frames or by adding removable screen frames. Screening of existing houses and other structures requires custom-made fittings. A disadvantage of removable screens is that householders may only install them at night as a measure against night-biting nuisance mosquitoes, whereas container-breeding *Aedes* vectors bite during the day. For this reason, permanent fitted screens are preferable. Another strategy is to improve building standards so that screening of windows and doors is included in new constructions.

There are many possible partners who may be involved in the implementation of house screening. These include householders, house rental agencies, hospital managers, ministry of education and school staff, hotel associations, and the private sector. A programme could promote house screening through a communication campaign aimed at raising awareness among the target group and providing guidance on how to mosquito-proof one's house or building. Where appropriate, special regulations could be enacted with respect to screening of high-risk sites, such as schools and hospitals.

Monitoring and evaluation

Screening of windows and doors could be monitored, for example, by the number of awareness-raising activities (and the level of participation in them), the amount of screening materials made available (e.g. to cover schools or hospitals), and progress made towards establishing regulations promoting or stipulating use of screening materials in specific settings. The coverage of interventions could be measured, for example, by the proportion of schools, hospitals and hotels in at-risk areas that have window screening installed, or the proportion of newly constructed houses fitted with window and door screens.

4.1.4 Targeted residual spraying

Residual spraying is targeted application of residual insecticides on surfaces, thus providing long-lasting control by killing adult mosquito vectors upon contact, reducing vector populations and lowering the risk of pathogen transmission. Indoor residual spraying, as commonly practised for malaria control in endemic countries, is not listed as a recommended method against *Aedes*-borne diseases (WHO, 2009). Nevertheless, an adapted type of residual spraying in the outdoor environment, known as “targeted residual spraying”, has evolved as an acceptable method against dengue vectors, even though there is a lack of clear evidence of its effectiveness in controlling dengue vectors or lowering transmission of dengue virus. This method of spraying has also been referred to as “perifocal spraying” (WHO, 2006b; Achee et al., 2015).

Targeted residual spraying is application of insecticides at or around specific resting or oviposition sites of the adults of container-breeding *Aedes* vectors. Resting sites would include, for instance, the surfaces of external walls or sheds, and vegetation in parks or backyards. Oviposition sites could be large containers that cannot be removed, or piles of used tyres awaiting reuse or disposal. For small containers, source reduction is the primary method of choice.

Effectiveness

There is a shortage of information on the effectiveness of residual spraying in the control of dengue, chikungunya and Zika transmission. Studies from Australia showed that the method was effective in prevention of *Aedes* breeding (Nguyen et al., 2009; Pettit et al., 2010). Moreover, there are reports from within the European Region that targeted residual spraying (with its larviciding and adulticiding effects), in combination with larviciding, was successfully used to eliminate new infestations of exotic *Ae. albopictus* populations, mostly at storage centres for used tyres (Scholte & Schaffner, 2007; Schaffner & Mathis, 2014).

When and where to use

Targeted application of residual insecticides is not considered an appropriate method for general use in managing established vector populations (Scenario 3), except as an interim measure to complement source reduction and larviciding in situations where vector population levels are unusually high.

The appropriate use of targeted residual spraying, in combination with source reduction and larviciding, is to create a treated barrier zone at points of entry (ports, overland crossings, etc.) in order to prevent introduction of exotic mosquito vectors (Scenario 1). In addition, there are indications that targeted residual spraying is crucial in eliminating small populations of established exotic vectors – again, when used in combination with source reduction and larviciding methods (Scenario 2). In areas where there are indoor-biting *Ae. aegypti*, indoor residual spraying could be considered by a programme as an additional method for emergency vector control – for example, to treat the house and surrounding houses of a sporadic case of locally transmitted dengue, spraying the undersides of furniture and dark corners where this vector prefers to rest. Depending on the insecticide compound and formulation used, the residual effect can last for several months. The problem with indoor spraying, however, is that acceptance among the public is likely to be low, because it requires temporary relocation of household furniture, measures to protect food and kitchen items are needed, and some people consider it a health risk and an infringement of their privacy.

Selection of insecticides

WHO has evaluated and recommended 23 insecticide products for indoor residual spraying against malaria vectors, which include pyrethroids, organophosphates and carbamates (WHO, 2018). WHO does not provide specific recommendations for residual spraying against *Aedes* vectors of arboviral diseases, but has suggested that suitable compounds can be selected from the list of products (excluding DDT) recommended against malaria vectors (WHO, 2006b).

Where spray operations involve a combination of larviciding and residual spraying, care should be taken not to apply adulticides in aquatic habitats and not to use larvicides for surfaces or vegetation, unless the compound has been recommended for both uses (which is the case for pirimiphos-methyl only). For example, pyrethroids have been recommended for residual spraying but not for larviciding.

Spray methods and equipment

Targeted residual spraying is typically aimed at small and specific areas to kill adult container-breeding *Aedes* vectors. Consequently, hand-operated compression sprayers should suffice for most purposes. For treatment of larger areas, such as stacks of used car tyres, motorized knapsack mistblowers are more efficient (WHO, 2006a).

Human safety and environmental protection

Residual spraying relies on the handling and use of chemical insecticides that are toxic to humans and the environment; most residual insecticide products are therefore not authorized for this purpose in countries of the European Region. Application should be carried out solely by trained personnel using certified spray equipment and personal protective equipment for handling and application of insecticides. Pyrethroids have a high toxicity to insects at very low dosages, while carbamates and organophosphates are applied at much higher dosages, with negative implications for non-target organisms such as birds and mammals. As residual spraying may involve overhead application of insecticides – to spray walls or bushes, for instance – spray personnel should be adequately protected, including with hat, face mask and gloves. In addition, safety precautions should be followed at preparation of the spray mix prior to the spray operation, and at clean-up after the spray operation (WHO, 2006b). To protect the environment, empty pesticide containers should be safely disposed of or recycled. Reuse of empty containers for unintended purposes should be avoided.

Monitoring and evaluation

The inputs and process of targeted residual spraying could be monitored through staff time invested, frequency of operations, types and area of surfaces covered by insecticides, amount of insecticide used, and the quality of spray equipment. Monitoring should also include bioassay cone tests of sprayed surfaces, and bioassay testing of insecticide susceptibility at sentinel sites. The efficacy of the intervention can be evaluated by comparing adult trap catches pre- and post-spraying at selected sites.

4.1.5 Emergency space spraying

Space spraying, or fogging, is the dissemination of small insecticide-containing particles (less than 30 μm) that remain airborne sufficiently long to make contact with flying and resting adult insects (WHO, 2011a). Space spraying is intended to create a cloud of minute aerosol droplets that produces a quick knock-down effect on mosquito vectors and so reduces their numbers. It uses very low dosages of chemical insecticide and hardly leaves any deposit on surfaces or vegetation; consequently, its residual effect is very limited (WHO, 2003).

Effectiveness

Considering that space spraying has been so commonly practised, both globally and in the European Region, it is remarkable that there is hardly any evidence on how and whether it works. Several systematic reviews concluded that there was no evidence to support the use of (mostly indoor) space spraying in dengue outbreaks (Erlanger et al., 2008; Esu et al., 2010; Pilger et al., 2010; Bowman et al., 2016). This does not necessarily mean that there is no effect of space spraying, but rather that there have been no trials of adequate quality that could demonstrate an effect on the vector or disease. As a consequence, the conditions under which space spraying might work, in relation to the treatment of outdoor or peridomestic habitats, are unknown; likewise, the requisite number of applications and the interval between them are unknown, as is the most appropriate part of the day or night for spraying.

One recent study of space spraying (which was of adequate quality), in which ultra-low volume (ULV) spraying was conducted during the night after thermal inversion (so as to avoid spread of spray droplets), demonstrated that repeated applications caused a substantial reduction of *Ae. albopictus* caught in BG-Sentinel traps (Farajollahi et al., 2012). During the 2016 outbreak of Zika in Miami, USA, aerial ULV applications of the organophosphate Naled produced short-lived drops in *Ae. aegypti* counts, but a stronger effect on the vector was found when combined with aerial application of the larvicide Bti (Stoddard, 2018).

Also, a retrospective analysis of 10-year surveillance data on dengue from a Peruvian city suggested that intensive space spraying, using ULV application of non-residual insecticide products and conducted inside 40% of the houses, helped accelerate the decline in dengue cases when carried out early in the dengue season (Stoddard et al., 2014). Nonetheless, solid evidence on epidemiological impact is still missing.

When and where to use

Space spraying is not suitable for most settings; it is recommended only in emergency settings of local transmission of arboviral diseases, such as dengue, chikungunya or Zika (Scenario 4), or in extreme nuisance conditions after emergencies (e.g. after recent hurricanes in the Caribbean). In an emergency setting, space spraying may potentially be added as a supplementary method to the main vector control methods of source reduction, larviciding, house screening and targeted residual spraying (refer to Section 5.4).

In locations where there are likely to be viraemic cases in the presence of an adult vector population (e.g. where locally acquired cases occur), the contribution of space spraying, when properly implemented, is to provide a rapid knock-down of potentially infected females vectors. This should have an immediate impact on transmission, at least during the short activity period after spraying. However, the epidemiological significance of these spray events remains to be studied.

The predominantly outdoor-biting *Ae. albopictus* could be targeted with outdoor space spraying. Indoor or peridomestic space spraying, targeting *Ae. aegypti* and possibly *Ae. albopictus*, can be very complicated in modern-type houses, considering the necessary safety precautions (WHO, 2003). Moreover, the coverage achieved by an indoor space spraying intervention is likely to be reduced by poor acceptance rates among residents.

Selection of insecticides

WHO has recommended seven pyrethroid products and two organophosphate products for space spray applications (WHO, 2018). The selection should be based on several considerations, including community acceptance, adverse effects on the environment, and susceptibility status of the target vector. Rotation of selected insecticides will delay the development of insecticide resistance within the vector populations.

Spray methods and equipment

Space spraying is mostly implemented using one of two main techniques: cold fogging and thermal fogging. A cold fog, or ULV application, is a liquid, usually water-based spray in which the spray mix is mechanically broken up into tiny droplets. A cold fog is applied at 0.5–2 L/ha using ULV insecticide formulations. A thermal fog is a liquid spray, usually oil-based, that is vaporized under high temperature and applied at much higher volumes of 5–10 L/ha (WHO, 2003). Because of its lower volume, cold fog is more efficient than thermal fog, but it is also more technically demanding.

Special space spray equipment includes portable and vehicle-mounted cold foggers (aerosol generators), and portable and vehicle-mounted thermal foggers (WHO, 2003; 2006a). Maintenance and calibration of spray equipment are essential in order to achieve small droplet size and correct dosage, particularly for cold fogging.

Space spraying requires skilled staff who are trained in safety precautions, handling of insecticides and equipment, and application techniques. Application should be carried out during the time of day that the aerosol remains airborne for as long as possible, which is normally dawn or dusk, or night-time. Ideally, the time of spraying should coincide with the activity period of the target vector species, but cold fogging could also target outdoor-resting *Aedes* mosquitoes during the night (Farajollahi et al., 2012).

Human safety and environmental protection

Spray teams conducting space spray operations must be fully protected against exposure to the insecticide, using gloves, masks, hats and protective long-sleeved clothing. Moreover, a respirator, with regularly cleaned filter, must be used during the actual spray operation, to reduce inhalation of insecticide droplets (WHO, 2003). Communities targeted for space spraying should be informed in advance about the operations, compliance measures, and level of risk, so that they can make a considered decision on acceptability.

Monitoring and evaluation

Space spray operations require careful monitoring of the conditions during the operations (e.g. wind speed, time of day/night), amounts of insecticide used, frequency of operations, and locations covered (WHO, 2003). Susceptibility of targeted vectors to available insecticide products should be regularly monitored. The effect of the intervention can be evaluated by comparing adult trap catches pre- and post-spraying at selected targeted sites.

4.1.6 Other potential methods

A number of other options exist for which less evidence is available about their effectiveness in controlling the vectors or disease. In specific settings, these methods could be considered as supplementary to the main interventions.

Mosquito traps

Mosquito traps used for surveillance purposes can potentially play a role in reducing vector populations by mass luring and trapping of vectors. In Brazil, mass trapping using BG-Sentinel traps had a modest (though not statistically significant) effect on the abundance of *Ae. aegypti* (Degener et al., 2014). More promising findings have been reported for lethal ovitraps, which are ovitraps modified to be lethal to gravid females and larvae (Perich et al., 2003; Kittayapong et al., 2008; Rapley et al., 2009; Ritchie et al., 2009). In Queensland, Australia, lethal ovitraps have been successfully used for vector control since 2004 (Queensland Health, 2011). In light of this, lethal ovitraps, when deployed in large numbers, are a promising tool for vector control (Scenarios 3 and 4) – a fact that merits operational research in countries of the European Region. Lethal ovitraps could be used at points of entry to lure and kill any exotic *Aedes* vectors upon arrival (Scenario 1); or they could be used in the elimination of locally established populations of exotic mosquitoes (Scenario 2) by trapping and killing the last remaining specimens.

Insecticide-treated materials

Insecticide-treated bed nets have been developed to protect people sleeping under the nets against mosquito bites. However, *Aedes* species bite mostly during the day, so such nets are not expected to provide personal protection against their bites except to those sleeping during the day (such as young children and hospital patients). Nevertheless, insecticide-treated bed nets may be able to reduce *Ae. aegypti* numbers (Wilson et al., 2014) – for example, when the nets remain in a hanging position during the daytime, thus killing mosquitoes that land on them. Bed nets also protect viraemic patients at home and in hospitals against biting mosquitoes and are thus required to prevent further transmission and outbreaks. Insecticide-treated netting used as curtains also has potential to reduce *Aedes* populations indoors (Wilson et al., 2014).

Topical repellents

Topical repellents applied to skin or clothing can provide individual protection against biting *Aedes* vectors and are recommended as an additional measure in emergency situations at locations of sporadic disease cases or outbreaks (Scenario 4). However, there is currently no evidence that topical repellents reduce the risk of dengue infection (Bowman et al., 2016).

4.1.7 Vector control tools under development

During the international Zika public health emergency in 2016, WHO recommended piloting the deployment of two new methods for control of *Aedes*-borne diseases, provided that such testing was accompanied by independent monitoring and evaluation (WHO, 2016a). While this emergency came to an end, evidence is still being generated on new tools for *Aedes*-borne disease control.

One of these new methods is biological control of human pathogens in adult mosquitoes by introduction of *Wolbachia* spp. bacteria into *Aedes* populations. Certain strains of *Wolbachia* have potential to substantially reduce the competence of *Aedes* spp. to act as vectors of dengue, chikungunya and Zika, by interfering with pathogen transmission and reducing the lifespan of adult mosquitoes.

The second new method involves use of a transgenic strain of *Ae. aegypti* mosquitoes. Transgenic mosquitoes are mass-released in the field for mating with the wild population, thus changing the gene pool. Any offspring with the new gene will die before adulthood under field conditions.

Other tools being developed include the sterile insect technique (SIT), odour-baited mosquito traps for disease control, and attractive toxic sugar baits. SIT, in particular, has been successfully tested in Italy and has caused suppression of populations of *Ae. albopictus*. The method is also being tested in France and Germany, and Albania, Greece, Montenegro and Turkey plan to do so in the near future (E. Dikolli, Institute of Public Health, Tirana, Albania, personal communication, 2018). However, these new methods require further assessment, in particular on their ability to prevent or control disease transmission, before they can be recommended for deployment at pilot scale for *Aedes*-borne disease control (WHO, 2016a). SIT should not be considered for emergency situations, unless the sterile males can be obtained from a sterile male production facility that is in full operation.

4.2 Control methods against other mosquito vectors

Methods to control container-breeding *Aedes* vectors do not necessary apply to other mosquito vectors in the European Region. Table 9 shows other mosquito vectors, excluding the container-breeding *Aedes* vectors covered in Section 4.1. The list is not exhaustive, showing only the main species that are potential vectors of disease.

Table 9. Main mosquito vector species (excluding container-breeding *Aedes* vectors), their breeding habitats and potential diseases transmitted

Species	Habitats	Diseases (potential)[a]
Ae. vexans *Ae. caspius*	Flooded meadows and ditches (temporary freshwater pools)	RV, *DI, WN*
An. atroparvus *An. labranchiae* *An. sacharovi* *An. maculipennis s.s.* *An. messeae*	Semi-permanent water bodies with vegetation, edges of slow-running water, ponds, fountains	MA, *DI*
An. superpictus	Natural and artificial water collections, preferably exposed to sun	MA
An. plumbeus	Tree holes, containers with water and dead leaves, abandoned cesspits	MA*, WN*
Cx. pipiens s.l.	Containers, ponds, marshes, flooded meadows, catch basins, flooded basements, cesspits	WN, RV, DI, SI

[a] **DI** Dirofilariasis **RV** Rift Valley fever **WN** West Nile fever
MA Malaria **SI** Sindbis virus

Normal font indicates proven vector.
Italic font indicates diseases for which the mosquito is a potential vector.

Source: Krüger et al., 2001; ECDC, 2014

Ae. vexans, together with other potential vectors with similar breeding ecologies, such as *Ae. caspius, Ae. cinerius* and *Ae. sticticus*, can proliferate in floodplains along rivers and streams, and adult mosquitoes can disperse in large numbers and over considerable distances. These “floodplain” mosquitoes are widely known for the nuisance problem they cause to residents in affected areas. The focus of this manual, however, is not on the nuisance problem but on the role of these species as vectors of emerging human diseases. Where locally transmitted cases of mosquito-borne disease (e.g. West Nile virus) have been reported from locations within 10–20 km of floodplains where *Ae. vexans* and associated species breed, control measures could be justified from the public health point of view.

Possible control measures against these floodplain breeding species are source reduction through drainage of flooded fields, where practicable and acceptable; and larviciding using bacterial insecticides, to minimize adverse effects on ecosystems. In the Upper Rhine Valley, mosquito nuisance control in floodplain areas has, over several decades, relied on aerial applications of Bti formulations, achieving an estimated 95% reduction in mosquito abundance (von Hirsch & Becker, 2009; Becker et al., 2010). Since 2003, mosquito samples from this area have been subjected to laboratory tests to detect the arrival of West Nile virus; the tests indicated that the virus had not arrived by 2010 (Timmermann & Becker, 2010).

Another group of mosquito vectors is the *An. maculipennis* complex, with *An. atroparvus* throughout most of Europe, and *An. labranchiae* and *An. sacharovi* in the southern, subtropical parts of the Region (Jetten & Takken, 1994). This group also includes the widespread *An. maculipennis s.s.* and *An. messeae* (Jetten & Takken, 1994; Gratz, 2004). These night-biting mosquitoes, which breed in habitats such as bodies of stagnant and clean water (fresh or brackish), river margins and rice fields, were in the past considered to be the major vectors of malaria parasites in the Region.

To control species of the *An. maculipennis* complex, methods could be used that target the immature stages or the adults feeding and resting inside houses and stables (Table 10). Suitable control methods include source reduction by draining or filling of water pools; larviciding of habitats that cannot be filled or drained; environmental modification, by clearing the edges of streams; and house screening and use of bed nets to protect against infective bites.

Table 10. Suitable methods for control of mosquito vectors (excluding container-breeding *Aedes* vectors)

Species	Source reduction	Environmental modification	Larvi-ciding	House screening	Bed nets
Ae. vexans	(✓)	✓	✓	–	–
An. atroparvus, An. labranchiae, An. sacharovi, An. maculipennis s.s., An. messeae	✓	✓	(✓)	✓	✓
An. plumbeus	✓	✓	–	✓	✓
Cx. tritaeniorhynchus	✓	✓	✓	✓	✓
Cx. pipiens s.l.	✓	✓	✓	✓	✓

An. plumbeus has been seen as a minor malaria vector. Recent reports, however, indicate an increased abundance of this species near human habitation, with high biting rates around dusk. This increased abundance is probably due to expansion of its breeding habitats, which include human-made habitats rich in organic matter as well as tree holes in public parks (Dekoninck et al., 2011; Schaffner et al., 2012). This species is a competent malaria vector, and its abundance near human hosts may increase the risk of parasite transmission.

The most suitable method for control of *An. plumbeus* is source reduction, through a variety of locally appropriate measures. Specific methods involve filling of tree holes in public parks, filling of rubbish dumps, and maintenance or demolishing of animal stables. Where source reduction cannot provide immediate control, it could be complemented with larviciding.

Cx. pipiens exploits a wide variety of aquatic habitats, from human-made containers to pools, flooded fields and swamps. It is considered the primary vector of West Nile virus for humans and horses in the Region, although another *Culex* species is maintaining the cycle in birds.

Cx. tritaeniorhynchus is commonly known for its role in transmission of Japanese encephalitis in South and South-east Asia; it is a new arrival in Europe with, to date, a limited distribution. This outdoor, night-biting mosquito species feeds primarily on birds (as do most of the *Culex* genus), but it also commonly feeds on large mammals, such as cattle and pigs, and occasionally on humans. It is known to breed in a variety of sunlit water bodies, such as ground pools, swamps, rice fields and ditches (Becker et al., 2010).

Both *Culex* vectors are controlled through source reduction, larviciding and, additionally, the use of bed nets and house screening.

5. Strategies for implementation of vector control

Prevention and control of invasive or native mosquito vectors require appropriate strategies for implementation, tailored to each of the four scenarios (see Table 2):

- Scenario 1: there is risk of introduction
- Scenario 2: the exotic vector has been introduced and become locally established
- Scenario 3: the vector has become widely established or is native
- Scenario 4: there is local transmission of mosquito-borne disease pathogens.

The strategy for each scenario consists of situation analysis; selection of vector control methods; and identification of needs, resources, roles and responsibilities in line with the principles of the strategy on integrated vector management (IVM) (WHO, 2012d).

5.1 Scenario 1. Vector not established

In Scenario 1, a vector species is not established in a particular country, but there is a risk of introduction and establishment via points of entry, such as seaports and airports, cross-border road and railway corridors, and storage sites for imported goods such as used tyres. The aim of the strategy is to prevent, wherever possible, introduction of exotic mosquito species and to eliminate any introduced mosquitoes upon arrival.

5.1.1 Situation analysis

Understanding the situation of a country with respect to possible introduction and establishment of exotic mosquito vectors is paramount in developing an appropriate strategy for prevention and control.

Points of entry include those designated under the International Health Regulations (IHR); at and around these locations, a country is obliged to put in place methods and procedures for surveillance and control of vectors and vector breeding reservoirs (WHO, 2005b).[2] Other potential points of entry for introduction of exotic mosquitoes include railway stations, and car parks and petrol stations along roads that originate in or pass through countries or areas colonized by invasive mosquitoes.

First, the potential invasive mosquito species should be short-listed, based on available knowledge, according to the suitability of climatic and environmental conditions in the country (including indoor habitats such as greenhouses). In particular, the ability of an exotic species to survive through the winter period will be an important indicator of its potential to become established. For each of these short-listed species, it is critical to understand how it might be imported by road, train, air or ship, and whether it is associated with specific imported goods. Then, possible import routes and geographical areas of origin should be determined, and points of entry identified. Determination of the country of origin of goods may be difficult if goods have passed customs clearance in one EU country before being transported to another EU country.

[2] See, in particular, IHR, Articles 19–21 and Annex 1B.

Available surveillance data taken from points of entry should be used to conduct retrospective analysis of the frequency and seasonality of previously introduced exotic mosquito species and to gain information on pathways and high-risk goods. Surveillance data should also be used to gain information on native mosquito species present in the vicinity of points of entry, as some native species may resemble invasive species (ECDC, 2012; 2014).

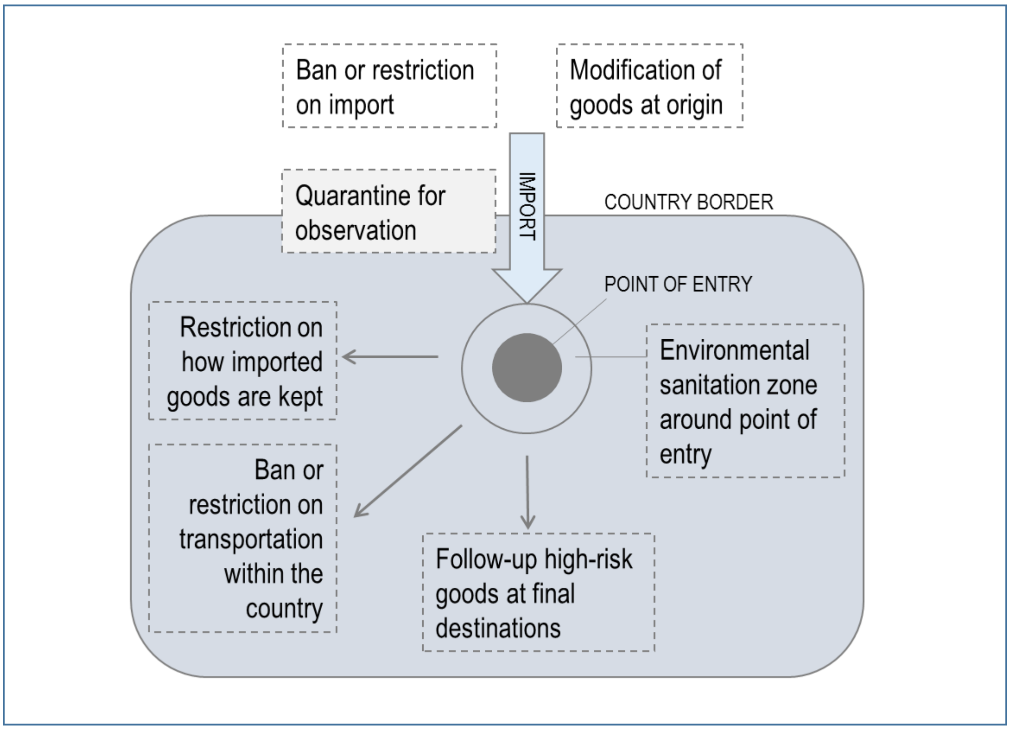
Rapid risk assessment, based on existing knowledge of the mosquito species, helps to assign a threat level to each potentially invasive species. This threat level depends not only on the likelihood of introduction and establishment of a species but also on its dispersal potential, its competence as a vector of human diseases, and the suitability of climatic and environmental conditions at points of entry (ECDC, 2012; WHO, 2016d). For example, it would be critically important to prevent and control *Ae. aegypti* at points of entry, as it is a competent vector of dengue, chikungunya and Zika, whereas prevention and control of *Ae. atropalpus* would be relatively less critical.

5.1.2 Selection of methods of prevention and control

The selection of methods for prevention and control of invasive mosquitoes at points of entry depends on the species targeted. In most countries of the European Region, the exotic vectors with the highest threat level are likely to be container-breeding *Aedes* species. Methods of prevention and control are selected on the basis of various criteria, including effectiveness, feasibility, acceptability and safety.

Countries may decide to proactively prevent introduction of exotic mosquito vectors before their arrival at points of entry. There are several possible methods and approaches to prevent introduction, as illustrated in Fig. 3.

Fig. 3. Potential strategies and interventions to prevent introduction of invasive mosquitoes



Source: WHO, 2016c

Evidence on whether such methods or approaches are effective in prevention of invasive mosquitoes is mainly lacking. Prevention is only practicable in cases where the mosquito is introduced with specific goods. This is the case with container-breeding *Aedes* species, which are commonly imported at the egg stage inside used car tyres or on specific plant products (e.g. *Dracaena* spp., including lucky bamboo). The eggs of a species such as *Ae. albopictus* have the ability to enter into diapause and survive long periods in the absence of water, which allows them to be transported over long distances.

Ban or restriction. Prevention could be attempted through a ban or restriction on import of high-risk goods. For the two known high-risk goods – used tyres and lucky bamboo plants – there are few known examples of a ban or restriction at country or local level. Importation of lucky bamboo plants in standing water has been prohibited by authorities in California, USA. A few countries have reportedly banned or restricted the import of used tyres to reduce the spread of mosquito-borne diseases (Murphy et al., 2011). Brazil banned imports of retreaded tyres as a measure to reduce breeding of local disease vectors, but in 2007 this measure was reversed by the World Trade Organization.

Modification. Modification of goods at point of origin could be an option for specific goods. This option has been used for the export of lucky bamboo plants from China to California. In this arrangement, the Californian authorities collaborated with the exporting companies in China to ensure that the plants were not shipped in standing water; instead, a gel was used to maintain adequate humidity. However, in the Netherlands this technique was not found to be effective in preventing introduction of *Ae. albopictus* (Scholte et al., 2008).

Quarantine. Imported goods could be quarantined for a fixed period to ascertain that they are free of invasive mosquito life stages. In Italy, local regulations on quarantining of used tyres have been implemented (Murphy et al., 2011). It is not known how effective this approach is in dealing with the diapausing eggs of *Ae. albopictus*.

Final destinations. Most goods are transported in freight containers. At points of entry, these containers are often left unopened and unchecked; they are then transported to their final destination, where they are opened for the first time. In the case of high-risk goods, these freight containers should be checked at ports or followed up at their final destinations.

Storage. Countries could impose special restrictions on how high-risk imported goods are stored after they arrive at their destination. Rather than banning imports of used tyres, a country could introduce a strict stipulation that imported used tyres are kept covered and sheltered from rainwater that could prompt the emergence of *Aedes* eggs present inside the tyres. Available insecticides are not effective at killing the hardy eggs of invasive *Aedes* species.

Transportation. Countries could consider restrictions on transportation of high-risk goods within the country – for example, by preventing used tyres from being stored in areas where *Ae. albopictus* has not been reported.

Sanitation zone. Under the IHR, it is stipulated that countries should establish programmes to control vectors to a minimum distance of 400 m from point-of-entry facilities (WHO, 2005b). At points of entry, the main strategy to prevent introduction of invasive mosquitoes is to create an environment that is inhospitable to incoming mosquitoes; this is achieved by means of vector control through source reduction, complemented by larviciding and targeted residual spraying.

5.1.3 Planning

Prevention and control activities should be planned and adapted to meet local seasonal conditions. Invasive mosquitoes may be introduced from other parts of the world at any time of year, but the environment is most favourable for exotic mosquitoes to flourish and establish themselves in an area during the warmer parts of spring, summer and autumn.

Planning procedures involve mapping and demarcation of areas at risk, and scheduling of type and frequency of operations. The IHR recommends a 400-metre zone around facilities that are used for operations involving travellers, conveyances, containers, cargo and postal parcels. This recommendation could be extended to car parks and petrol stations at country borders on roads that originate from colonized areas (ECDC, 2012). Frequency of source reduction and larviciding operations depends on the season – the mosquito life cycle is shortest during the summer months. As a general rule, the frequency should be every 2–3 weeks during spring, summer and autumn.

Source reduction should generally be considered the main control measure at points of entry, to ensure that any incoming mosquitoes are not able to find suitable aquatic breeding sites. Source reduction around ports includes routine checking and removal of scrap, structural modification of terrain to prevent standing water, covering of tyres, and replacement of tyres used as fenders (or, as a temporary measure, perforating tyres used as fenders to avoid standing water) (WHO, 2016d).

Where source reduction is not possible or desirable, larviciding of aquatic breeding sites should be conducted routinely, preferably using bacterial larvicides, spinosads or IGRs, to prevent breeding of exotic mosquitoes. Another supplementary method of control is targeted residual spraying of specific structures or vegetation preferred for resting by targeted mosquito vectors. The frequency of residual spraying will depend on the residual activity period of the insecticide used (WHO, 2017b). Use of trapping devices for surveillance purposes at points of entry could also play an additional role in luring and trapping of any incoming mosquitoes.

Detection at a point of entry of one or more specimens of an exotic mosquito vector species that has not previously been recorded in the country is the trigger for stepping up the vector control effort, through intensified source reduction, larviciding and residual spraying, with the aim of eliminating all introduced mosquitoes. Stepped-up vector control action is continued until surveillance data confirm that the invasive mosquito has been eliminated.

5.1.4 Needs and resources

Routine surveillance, prevention and control at ports and other points of entry require teams that assume responsibility to carry out routine inspection, sanitation and control activities. Initial clean-up, or recurrent clean-up after each winter off-season, requires additional resources and equipment to remove and dispose of scrap or bulk waste from the area.

The teams require initial and regular refresher training on surveillance, prevention and control activities, including training on insecticide application methods and safety precautions. The relevant authorities should ensure adequate supervision, independent monitoring, and a mechanism for feedback of monitoring results. Insecticide products and spray equipment should be managed to ensure availability for routine applications and in emergencies.

5.1.5 Partners in implementation

The national IHR focal point, with support from national experts, has a role in providing supervision, technical guidance and independent evaluation of the surveillance, prevention and control activities at all designated and non-designated points of entry. Entomological institutions and laboratories are required to assist in the identification of native and exotic mosquito species. Mosquito surveillance activities conducted at each point of entry should be linked through data sharing and a national database containing information on introduced mosquitoes.

Port authorities and service providers at facilities for travellers and cargo should be involved in prevention and control of vector mosquitoes in their areas of work (WHO, 2016d). Other partners include customs officials, who can inform inspection teams on quantities, types and origins of high-risk goods. Contractors could be involved in clean-up of scrap or in implementing structural modifications and drainage improvements around ports.

5.1.6 Monitoring and evaluation

Prevention of introduction of invasive mosquitoes can be monitored through records of staff time invested; type and number of traps, and frequency of trapping; time taken for identification of samples and feedback of results; and coverage and frequency of source reduction, larviciding and residual spraying operations. The number and percentage of follow-up observations of containers with high-risk goods at arrival and/or at final destination should be recorded. It is also important to monitor progress made in rapid risk assessment, mapping and demarcation of designated points of entry, and to monitor activities aimed at raising awareness of invasive mosquito prevention and control among authorities and service providers at points of entry.

Evaluation of the efficacy of preventive efforts is conducted by analysis of trap catches of indigenous and exotic vector species at designated points of entry, as well as at final destination sites of containers with high-risk goods (e.g. importers of used car tyres).

5.2 Scenario 2. Vector locally established

In Scenario 2, an exotic vector species has been introduced and established itself in one or a few small areas, and there is no evidence of widespread dispersal. In this scenario, the aim of the strategy is to decide whether or not a fully fledged elimination effort should be undertaken and, if yes, how it should be implemented and evaluated.

5.2.1 Situation analysis

Suppose that – despite preventive and control activities at points of entry – a mosquito vector has entered the country; if these introduced mosquitoes successfully blood-feed and find suitable breeding sites, they could become established. Upon arrival in a new environment, a mosquito species will normally go through a period of colonization during which it adapts to its new environmental and climatic conditions (ECDC, 2012).

During this adaptation period, the small mosquito population is relatively vulnerable. This is the time at which a fully fledged elimination effort should be implemented and completed. If the exotic mosquitoes are allowed to colonize and adapt, they may disperse into new areas. It would then be much more difficult to successfully eliminate the species.

Once surveillance activities have confirmed the presence of an invasive mosquito species in an area, intensive surveillance should be carried out without delay to determine the extent of its dispersal. This phase involves setting an increased number of traps in several concentric circles around the area where local establishment has been confirmed. If the traps placed furthest from the initial area catch the invasive species, additional traps should be set even further away. The distance at which the species is no longer caught demarcates the perimeter of the locally established population.

In this way, the infested area should be defined and mapped. Traps positioned in the space surrounding the demarcated area are used to confirm the absence of the invasive species, indicating that further dispersal has not yet taken place.

In addition, situation analysis of the demarcated area should include data on human habitation, and geographical and environmental variables, to determine the potential breeding and resting sites of the invasive mosquito. This information will be needed for optimal selection of vector control methods.

5.2.2 Decision-making

The objective of elimination is to reduce the mosquito density to such a low level that any remaining females cannot be located by males or are unable to locate productive breeding sites. This results in local extinction of the population.

As a rule of thumb, elimination of local populations of invasive mosquitoes is feasible if the area of establishment is 1 km² or less. This suggests that early detection of local establishment and prompt elimination action are of the essence. For mosquito vectors that pose a high threat, such as *Ae. aegypti*, which is a very efficient vector of dengue virus, elimination over considerably larger colonized areas could still be justified. When the colonized area is more than 25 km², the population may be regarded as locally established (ECDC, 2012).

It is noteworthy that, in the first half of the 20th century, invasive mosquitoes were eliminated from much larger areas. For example, *An. gambiae* was eliminated by larviciding from an area of 54 000 km² in north-east Brazil in the 1930s (Killeen et al., 2002) and from Egypt in the 1940s (Shousha, 1948). However, these operations relied on methods that would be unacceptable today, as they depended heavily on use of highly toxic and chemically persistent larvicides, and militaristic-style operations. Furthermore, urbanization and widespread use of plastics have greatly multiplied the number of available artificial breeding sites.

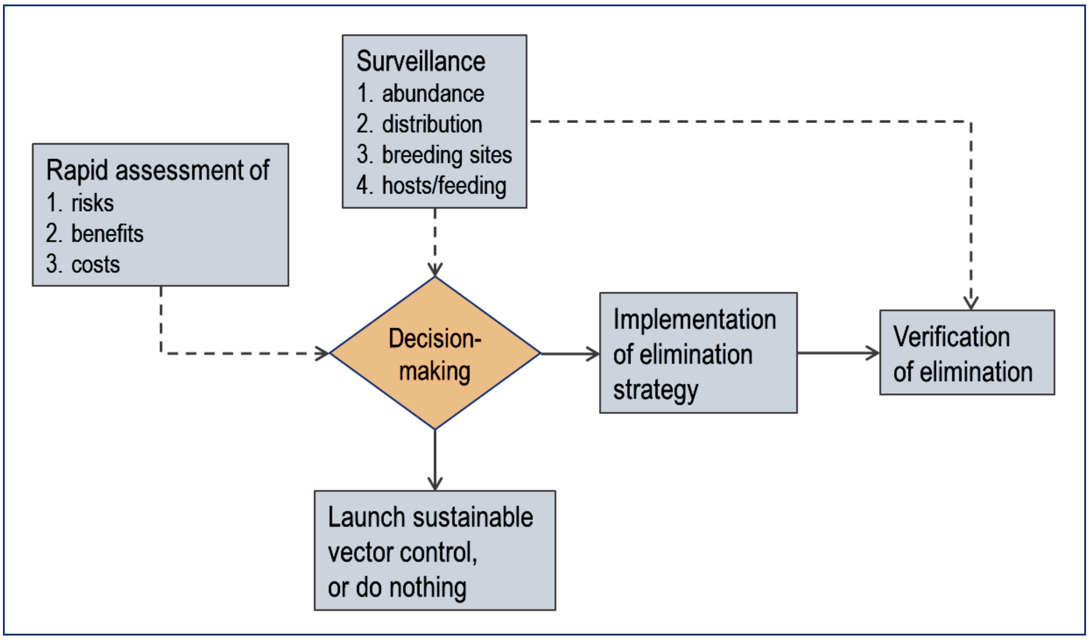
A rapid risk assessment helps to gain information about the potential treat of the exotic mosquito vector to human health, animal health and biodiversity. Such an assessment should take into account information available from other countries about the competence and efficiency of the vector in transmitting human diseases, its host range and dispersal potential. This information should be evaluated alongside conditions in the area of local establishment.

A budget estimate of the costs of an elimination effort should be prepared. Costs include staff time for surveillance, clean-up and insecticide application in the demarcated area; training; evaluation; transport; insecticides; and equipment.

To guide the decision-making process, decision rules should be prepared and ready for use when needed. Decision rules could establish, for each anticipated species of invasive mosquito vector, an approximate cost that would be justified for an elimination effort, and the implications of that cost for the maximum area to be covered by intensive surveillance and control actions. In this context, a distinction could be made between port and industrial areas, urban (or peri-urban) and rural areas, tourist areas, and settings with foreign workers or unplanned human displacements. In urban settings, mosquito surveillance and control activities are often complicated by restricted access to private properties.

Using these decision rules, together with surveillance and mapping data, it can be determined whether or not to embark on elimination. If it is decided that elimination is appropriate, it must be a fully fledged effort – a half-hearted effort is likely to be a waste of resources. A schematic plan for elimination of foci of colonization is illustrated in Fig. 4.

Fig. 4. Schematic plan for elimination of foci of colonization



Source: WHO, 2016c

5.2.3 Selection of vector control methods

Suitable control methods for eliminating locally established exotic mosquitoes include source reduction, larviciding and targeted residual spraying. Source reduction is the primary method, with the objective of removing, draining or filling containers and vessels that could be used for breeding. Aquatic habitats that cannot be removed, drained or filled are treated with bacterial larvicides, spinosads or IGRs.

As a supplementary measure, targeted residual spraying, applied to places where adult mosquitoes rest or in the vicinity of oviposition sites, aims to achieve an immediate impact on the adult mosquito population. Targeted residual spraying has proved to be effective in eliminating local mosquito populations in stacks of used car tyres. Luring-and-trapping devices used for surveillance purposes are also beneficial in the elimination effort, as a means of killing the last remaining specimens.

5.2.4 Needs and resources

A mosquito elimination plan should be ready to be activated during spring, summer and autumn, with sufficient resources available to support a fully fledged implementation capable of achieving and verifying elimination. Another requirement is training of teams to conduct surveillance, inspection and vector control activities, including training on insecticide application methods and safety precautions.

5.2.5 Partners in implementation

Depending on location and setting, implementation of a mosquito elimination plan may involve port authorities, municipalities and contractors in cleaning up bulk waste, scrap and other containers that could serve as vector breeding sites. A country or region should have dedicated teams trained in surveillance, inspection and vector control, ready to be deployed to focal sites where invasive mosquitoes have been detected.

Box 1. Elimination efforts – successful and unsuccessful

A number of examples of successful elimination of invasive mosquitoes have been mentioned in the literature, predominantly relating to container-breeding *Aedes* vectors. Unfortunately, these documented examples do not provide much detail on what made these operations successful.

Infestations of *Ae. albopictus* and *Ae. japonicus* at tyre-recycling companies or at storage sites for imported used tyres have been successfully controlled in several examples from France, using a combination of spraying with larvicides and adulticides (Vazeille et al., 2008; Schaffner & Mathis, 2014). In the Netherlands, three species of invasive mosquitoes – *Ae. aegypti*, *Ae. albopictus* and *Ae. atropalpus* – were recorded in companies that import used tyres; they were eliminated by removal of larval habitats in a 500-metre perimeter surrounding the sites, combined with application of bacterial larvicides in the remaining aquatic habitats, repeated every 2–3 weeks, until the end of the season (Scholte et al., 2010). In Belgium, *Ae. japonicus* has repeatedly been found at used-tyre companies since 2002, but because it did not propagate, control efforts were only initiated in 2012 (Versteirt et al., 2009; Kampen & Werner, 2014).

There are also examples where elimination of an invasive mosquito was not successful. *Ae. aegypti* invaded Madeira in 2004 and dispersed over the island. Vector control was implemented through reduction of breeding sites, insecticidal treatments for immature and adult forms, and public health education, but the vector was not reduced or eliminated and is still thriving (Almeida et al., 2007). In the Mediterranean basin, *Ae. albopictus* is thriving and gradually extending its range; consequently, elimination of this species is no longer considered feasible.

In countries around the eastern part of the Black Sea, where *Ae. aegypti* has become established and is spreading its range, a fully fledged elimination effort has not yet been initiated. Immediate measures are needed to stop, or at least slow down, further dispersal of this threatening species into new areas.

The national IHR focal point and its technical team may have an important role in supervision of elimination activities at designated points of entry. The role of academic institutions should be to provide technical guidance on surveillance and control actions, and to monitor and evaluate the elimination effort.

In accordance with a communication plan, residents and communities living within the area demarcated for mosquito elimination should be informed about the operations and made aware that their participation in source reduction activities is required.

5.2.6 Monitoring and evaluation

Elimination operations should be carefully monitored in terms of the type, scale and frequency of interventions used, staff time invested, and participation of other agencies. The success of an elimination effort depends on up-to-date surveillance data to inform the operations where elimination has likely been achieved or whether continued operations are required. Elimination is verified if the invasive species remains absent from trapping devices, which are used in adequate numbers, throughout the breeding season. Follow-up surveillance in the following season should establish whether the mosquito has been eliminated.

In view of the current shortage of detailed documentation of efforts to eliminate invasive mosquitoes, it is important that future efforts are adequately monitored, evaluated and then documented, to strengthen the evidence base for elimination and to add lessons learned. In the Netherlands and Belgium, where nationwide mosquito surveillance programmes are being conducted, invasive mosquito species have frequently been detected and controlled through rapid control actions.

5.3 Scenario 3. Vector established or native

In Scenario 3, the vector has become widely established (beyond an area of 25 km^2) or is native, and it is considered difficult to eliminate the species unless major resources are mobilized. In this scenario, there is no actual or ongoing transmission of mosquito-borne diseases, but with the vector present there is a constant threat that disease cases (such as malaria or arboviral diseases) from abroad may be imported into the country or area. Here, the objective is sustainable reduction of vector populations and reduced human contact with the vector. This will reduce the risk that imported pathogens in infectious individuals are transmitted from person to person.

5.3.1 Situation analysis

Routine surveillance data, taken from different parts of the country, provide information on the abundance and seasonal dynamics of mosquito vectors. These data are especially needed from areas where established or native vectors are known to be abundant during the breeding season. Mapping of surveillance data using Global Positioning System (GPS) coordinates enables stratification of areas along administrative or ecological boundaries; different actions or interventions may be appropriate for each stratum. Information on risk factors, such as favourable breeding habitats, tourism, foreign workers, unplanned human displacements and urbanization, provides important additional criteria to allow prioritization of areas, or specific localities, for mosquito control.

As part of the situation analysis, information on the competence of each vector species – either established invasive species or native species – should be gathered from available sources. A species may be confirmed as a vector of a given disease pathogen in the laboratory only, or its vector status may be verified in field samples. A species may be known as an efficient or minor vector, or as a possible or probable vector. Also needed is information on flight range, host range, preferred breeding sites of a species, and the actual presence of breeding sites in the vicinity of human habitation.

In addition to information on geographical distribution and biological characteristics of mosquito vectors, the risk of imported disease cases should be assessed. Retrospective epidemiological surveillance data will show imported cases, their travel histories and their places of residence. This information may be used to predict the level of risk due to imported cases in areas where competent vectors occur.

5.3.2 Selection of vector control methods

The primary method to sustainably control established or native mosquito vectors is source reduction. This is implemented with the active participation of residents and other actors, by means of removal, draining and filling of human-made and natural containers, or other types of aquatic breeding habitats utilized by the mosquito vector (e.g. *Aedes*, *Anopheles*) in question. Where source reduction is not possible, or where vector abundance has exceeded a certain threshold level, larviciding may be a suitable supplementary method. When insecticides are used for vector control, the susceptibility status of the target vector to the insecticide compound must be verified. In areas with elevated risk of disease transmission, due to the presence or abundance of efficient vectors of emerging diseases, house screening should be promoted among householders and in schools, hospitals and workplaces.

The focus of this manual is control of vectors of human disease from a public health perspective; it is not control of nuisance biting. A number of countries in the European Region, particularly Mediterranean countries, already have programmes in place for control of mosquito nuisance (Becker & Zgomba, 2007). These ongoing abatement programmes certainly help reduce the risk of pathogen transmission, especially if the target mosquito is a vector of emerging diseases. However, the principal vectors of emerging diseases such as dengue, chikungunya and Zika are currently not targeted by many abatement programmes.

5.3.3 Action thresholds

Where there is no ongoing pathogen transmission, the important question is: what mosquito density level (threshold) must be reached before vector control action is taken to reduce the risk of transmission from imported cases? This action threshold, once established, will provide clear guidance to the vector control operations and avoid routine operations that do not take account of vector abundance.

Action thresholds are commonly used in the control of nuisance mosquitoes. In Germany, the threshold for the floodwater mosquito *Ae. vexans* is 50 specimens trapped in CO_2-baited light traps 2 km distant from human settlements (Becker et al., 2010). In Italy, public tolerance to mosquito biting intensity has been linked to light-trap catches, in order to provide an acceptable level of nuisance control (Carrieri et al., 2008; Becker et al., 2010). Action thresholds for mosquito nuisance control are not the same as action thresholds for vector control. For example, a mosquito vector population could have a significant capacity for pathogen transmission at a density which was hardly noticeable as a nuisance issue.

For dengue control, simple indicators for the presence of *Aedes* larval stages are not accurate for use as action thresholds. In the last two decades, improved thresholds have been developed for dengue-susceptible and dengue-endemic settings in other WHO regions. These improved thresholds are based on the “standing crop” of *Ae. aegypti* pupae per person (Focks et al., 2000). Similar thresholds could be developed in the context of the European Region, preferably under the guidance of WHO experts.

In the event that there is any locally acquired mosquito-borne disease case, the next action threshold has been crossed. Even a single case of local transmission should provide the trigger for activating emergency vector control operations, with the aim of preventing the locally present pathogen from being transmitted between human hosts. This is covered in more detail in the discussion of Scenario 4 (Section 5.4).

5.3.4 Planning and implementation

Actual planning for implementation is based on the situation analysis. Its aim is to target vector control in areas where vector populations are likely to be highest, and at times when proliferation is anticipated (principally for source reduction) or when vector density has gone beyond an acceptable threshold level (e.g. for supplementary larviciding). Information on local risk factors helps to fine-tune targeting of vector control operations (for instance, by targeting specific areas where there are foreign workers or tourists, schools, hospitals, public places, etc.).

The most appropriate vector control methods are selected on the basis of various criteria including efficacy, safety, acceptability, potential of participation, affordability, and risk of insecticide resistance (WHO, 2016c). Resources available for implementation of each method should be identified, including budgetary support, staff time, supplies and equipment, and technical skills. For each vector control method, the roles and responsibilities of the partners in implementation should be agreed.

5.3.5 Needs and resources

Routine mosquito surveillance and control activities require mosquito surveillance teams and teams coordinating vector control activities carried out by third parties. These teams require training and refresher training, including on insecticide application and safety precautions. Other requirements are transport, spray equipment and insecticides.

5.3.6 Partners in implementation

A number of partners may be involved in sustainable vector control (Scott & Morrison, 2010). In the case of container-breeding *Aedes* vectors, municipalities have a role in the clean-up of public places, weekly rubbish collection and occasional bulk waste collection. The education ministry, schools, hotel associations and civil society organizations could actively promote source reduction and personal protection measures, both at their premises and through awareness-raising campaigns. The media have a role in broadcasting information and messages about vector control. The task force, or vector control coordination unit, should maintain active links with all partners involved in sustainable vector control and coordinate their activities for optimal effectiveness.

5.3.7 Monitoring and evaluation

Monitoring of the implementation of vector control activities conducted by each partner helps to identify shortcomings and barriers encountered. This information, collected by independent entities, should be fed back to the vector control coordination unit and to the partner organizations, so that improvements can be made. Routine monitoring of vector densities and seasonal fluctuations provides information necessary for planning and targeting of vector control operations by the partners involved, and for evaluating the effectiveness of vector control interventions in terms of reducing vector density.

5.4 Scenario 4. Local disease transmission

In Scenario 4, there is evidence of locally transmitted, mosquito-borne disease cases. The disease pathogen has apparently entered the country by means of imported cases. If an incoming traveller is in the viraemic stage of an arboviral disease such as dengue or chikungunya, the disease-causing virus has been circulating in the person's bloodstream for a number of days. This is the infectious stage, and when the person is bitten by a locally occurring mosquito vector, such as *Ae. albopictus*, the virus may be spread to other people. The people who are infected by these vectors are the locally transmitted cases. The aim of the strategy in Scenario 4 is to contain the pathogen by interrupting transmission before more people become infected.

For arbovirus infections, a proportion of people infected do not show major disease symptoms; these asymptomatic cases can easily be missed by the epidemiological surveillance system. However, they can have the virus in their bloodstream and thus contribute to viral transmission (so-called silent transmission). For malaria, any person who has not recently been infected by malaria parasites is non-immune and will develop clear malaria symptoms after infection. These cases of malaria do not easily go unnoticed.

5.4.1 Situation analysis

Where one or more mosquito-borne disease cases have been reported, they should be confirmed through laboratory testing. Before the laboratory results are available, any possible or probable cases that have been clinically diagnosed should undergo case investigation. Based on the travel history of the person, it should be decided whether the case was imported or locally transmitted.

If the case was imported, no emergency vector control measures are needed, other than to prevent the patient from being bitten by any local vectors (for instance, by means of an insecticide-treated bed net).

However, if the case was locally acquired and has been laboratory-confirmed, the pathogen is present within the local vector population. While the pathogen has been circulating, more people may have been infected or are at immediate risk of being infected. Such evidence of local transmission provides the trigger for activation of an emergency response.

5.4.2 Emergency response

The emergency response, or outbreak response, consists of two components: emergency vector control, and early diagnosis and clinical treatment or case management. Epidemiological surveillance and emergency vector control should be closely linked. A multisectoral response action committee, with a political mandate, should be in place to coordinate the emergency response.

The emergency response starts with an exploration of the likely locations of transmission, which include the residence of the disease case and case contact points; contact points are places visited by the case during the infectious stage (e.g. school, workplace, family, friends).

Intensive vector surveillance is then conducted at and around the residence location of the infected person and at case contact points. This provides information on locally occurring vector species and their breeding habitats. If possible, vector surveillance should include screening for pathogens in mosquito specimens (ECDC, 2014). Such activities, however, should not delay initiation of vector control action. In the event of an outbreak, the area of the outbreak should be demarcated and intensive vector surveillance conducted within that area. Based on available data on mean distance travelled by *Aedes* spp. (Guerra et al., 2014), emergency vector control operations should be implemented within a 100–200-metre perimeter around the location of transmission, including around case contact points.

Simultaneously, active epidemiological surveillance in and around the localities of the index case (i.e. the person first noticed by the health authorities (ECDC, 2012)) is conducted to identify further possible and probable disease cases; these are then referred for laboratory confirmation and appropriate case management. The locations of new possible or probable cases inform the outbreak response team about the development of the outbreak, to guide the outbreak response action.

A communication campaign is important to inform the community in the area about the emergency response action, and to mobilize the community to take an active role in source reduction and personal protection (for example, by wearing clothing covering arms and legs, and by use of repellents).

5.4.3 Selection of vector control methods

The objective of emergency vector control is to deliver an immediate impact on the vector population in order to prevent any further transmission of the pathogen. Methods of vector control should attack the vector at both immature and adult stages for maximum impact.

As in the scenarios already discussed, source reduction constitutes the backbone of vector control, rendering the targeted locations unfavourable for vectors to proliferate. Aquatic breeding sites that cannot be removed, drained or filled should be treated by larviciding.

Adult female mosquito vectors that are infected with a disease pathogen (e.g. arbovirus, *Plasmodium*) remain infective during their lifespan. Hence, where there is evidence of local transmission, it is vital that the adult vector population is eradicated. Adult vectors can be killed by means of targeted residual spraying at resting sites and in the vicinity of breeding sites. In addition, emergency space spraying, when properly implemented, can have an immediate lethal effect on container-breeding *Aedes* vectors; it may, however, have to be repeated several times to effectively interrupt transmission.

As part of emergency vector control, infectious individuals should be protected against mosquito bites (for instance, by using an insecticide-treated bed net) during the period of vector biting.

5.4.4 Needs and resources

The results of a risk assessment will give information about the likelihood of sporadic cases or local outbreaks of mosquito-borne diseases (ECDC, 2014). Nevertheless, it is difficult to predict in advance the frequency of sporadic cases or the extent of outbreaks. Therefore, to be prepared for unexpected outbreaks, adequate emergency funds must be available for use when and where needed. Also, equipment and supplies should be ready for deployment, regularly maintained and restocked. An outbreak response unit, with appropriate training, should be present and ready for action.

5.4.5 Partners in implementation

To facilitate prompt action, it is essential that countries at risk of emerging mosquito-borne diseases have a dedicated outbreak response unit, with the task of directing and coordinating the response action. An outbreak response unit, including a national coordinator, requires multisectoral representation (see Section 5.6).

Clinics and hospitals should provide diagnosis and supportive care to arboviral disease cases, or medication to malarial cases, and refer clinical cases for laboratory testing. Clinics, hospitals and laboratories also have a role in reporting data on possible, probable and confirmed cases of mosquito-borne diseases, and a responsibility to ensure prompt diagnosis and laboratory testing.

Other partners in implementation of emergency vector control as part of an outbreak response are municipalities, hotel associations, the education sector and schools, civil society organizations, and the private sector.

5.4.6 Monitoring and evaluation

Observations and monitoring records should establish the time it takes from detection of a suspected case to case investigation and, if appropriate, to initiation of emergency response actions. In addition, monitoring should include the operation of active epidemiological surveillance at case contact points (noting the number of laboratory-tested and laboratory-confirmed cases), and the timing, frequency and coverage of emergency vector control operations. Outbreak investigation should evaluate flows of information, and mobilization of partner agencies and affected communities in the response action, in order to make suggestions for improvement in future emergencies.

5.5 Multiple scenarios

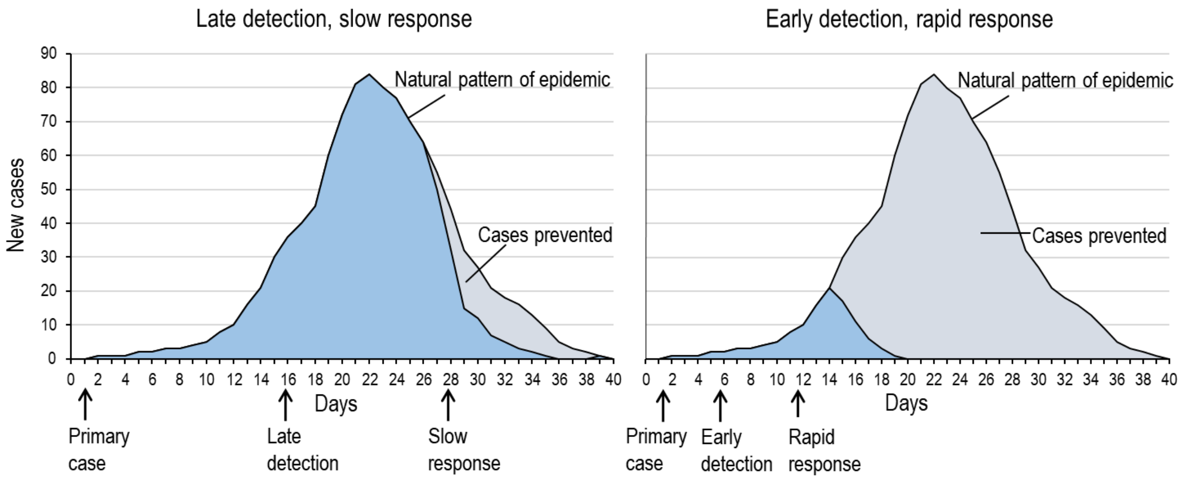
The previous sections (5.1–5.4) have looked at implementation strategies for each scenario. A common reality, however, is that a country may have to confront more than one scenario simultaneously. For example, a single country might be vigilant about possible introduction of *Ae. aegypti* at points of entry (Scenario 1); confront local pockets of newly introduced *Ae. albopictus* and *Ae. japonicus* (Scenario 2); and have populations of several native mosquitoes that are potential disease vectors (Scenario 3). Such a country would need a strategy for three different scenarios in the form of a combined strategy incorporating preventive measures at points of entry, elimination efforts targeting locally established species, and sustainable control measures directed at native vector species. The strategy pertaining to each scenario would have its own objectives and targets. By combining these individual strategies, a country could make efficient use of the available financial, technical and human resources.

5.6 Outbreak preparedness

Countries in the WHO European Region should be prepared for local transmission and outbreaks of mosquito-borne diseases. An outbreak or epidemic will follow a natural pattern unless timely response action is taken in order to reduce the number of cases (Box 2).

Box 2. Outbreak pattern – impact of slow and rapid responses

A theoretical model of an outbreak starts with an increase in the number of cases until the peak is reached. After the peak, the number of new cases begins to decline. This decline occurs because the remaining population that has not been affected is rapidly diminishing, with the result that the number of newly affected cases drops and the outbreak comes to an end. This is the natural pattern of an outbreak or epidemic.



If the detection of cases is delayed and the outbreak response action is slow, the positive impact of the response action is very small, as illustrated in the graph on the left (modified from WHO, 2012a). But if cases are detected early and the response action is quick, there may be a major positive impact, in terms of cases averted by the response action (right-hand graph).

Preparedness is important in each of the four scenarios presented above. At points of entry, invasive mosquitoes could facilitate pathogen transmission among infectious travellers from abroad, or the invasive mosquitoes themselves may have been infected upon their arrival (Scenario 1). Where an exotic vector is locally established (Scenario 2), it could facilitate pathogen transmission in that specific area. However, it is where there are established or native populations of mosquito vectors (Scenario 3 and 4) that preparedness is most critical.

A preparedness plan for outbreak response is crucially needed in all countries; it should be based on knowledge of the patterns of disease transmission, the biology of vectors, and clinical outcomes and management. After an infected mosquito has bitten, the pathogen needs a number of days to reproduce and become abundant in the bloodstream of the human host (internal incubation time). After this incubation time, the pathogen enters the infectious stage during which vectors biting the host can pick up the pathogen and may eventually become infected. For some pathogens (e.g. West Nile virus), this infectious stage is of short duration (a few days), while for others (e.g. malaria parasites) it can last several days or weeks, and mosquitoes can acquire the pathogen over many days. After being ingested by the blood-feeding mosquito, the pathogen needs to develop for a number of days inside the mosquito before the mosquito can infect another human (external incubation time).

Outbreak preparedness and emergency response depend critically on a routine epidemiological surveillance system, with capacity for early detection and reporting of cases. Once cases are detected, an emergency response should be rapid and coordinated.

For this reason, an outbreak response unit, or committee, should be in place, with a coordinating entity (e.g. a programme manager) and with representation from several sectors and agencies (WHO, 2009; Harrington et al., 2013). These representatives may include a health coordinator, a municipal authority, a clinician, a laboratory technician, a vector control specialist, a water/sanitation specialist, an educator, and representatives from civil society organizations and the private sector.

It is the responsibility of the outbreak response unit to be prepared to initiate and coordinate the response to sporadic cases or an outbreak of an emerging mosquito-borne disease. The unit should meet routinely to review surveillance data and other sources of information, and its meetings and activities should be stepped up when sporadic cases or an outbreak have been reported, in order to review data and investigation of cases. Triggers for activation of the response plan must be defined. In the context of the European Region, where endemic mosquito-borne diseases (with the exception of West Nile virus and Usutu virus) are absent, detection of a single locally acquired case of a disease is the trigger to activate the emergency response. When, following the response action, no more new cases are reported, a trigger for deactivation may be given by the outbreak response unit.

An outbreak response plan should give details of coordination mechanisms and responsibilities, and several types of action should be included in the response:

- enhanced disease surveillance;
- enhanced vector surveillance and control;
- management of the health system to deal effectively with an influx of clinical cases;
- case management, from mild to severe;
- a strategy for communication and community mobilization.

In each of these response actions, the roles and responsibilities of the relevant partner agencies should be defined. The outbreak response plan should be formally agreed by all government agencies. Training of staff and financial preparedness are essential, and in the absence of outbreaks it is essential that outbreak response staff conduct practical exercises to sustain their level of preparedness. Finally, the plan should also include a checklist of human resources, material and equipment (including diagnostic kits), and facilities needed in case of an outbreak.

Monitoring and evaluation conducted during an emergency response action are essential to provide feedback on what inputs and human resources were available; how and when they were used in the outbreak response; and what effect they had on the vector population, transmission intensity and the number of cases (WHO, 2005a).

6. Regulatory and organizational aspects

For effective prevention and/or control of invasive mosquito species, a rapid response upon detection of an invasive species (eggs, larvae, pupae or adults) is required to limit spread and reduce the likelihood of establishment. For such a response to be effective, a local, or preferably national, authority with decision-making authority should be available.

The WHO's Global Vector Control Response (GVCR) (WHO, 2017a) describes the process and leadership required to achieve an adequate response (see Section 6.2 below).

6.1 Regulation of vector control

Broadly speaking, there are at present no specific rules or regulations that govern prevention and control of mosquito-borne diseases in Europe, with the exception of the IHR stipulations (WHO, 2005b). Historically, countries endemic for malaria organized prevention and control of the disease through a provincial or national centre for malaria control, following guidance given by WHO. Since the disappearance of malaria from the European Region, most of these centres have been integrated into national health institutes, and in recent years occasional local outbreaks of malaria have been dealt with mostly at national level.

The ECDC has issued guidelines for surveillance of invasive mosquitoes that are very useful for early detection of such species (ECDC, 2012). There is a need for information on the steps that should be taken to control or eliminate invasive species, as countries may not have the expertise to estimate the health risk associated with potential establishment of such species and therefore lack the capacity to take adequate action.

Given the large variation in climate, topography and ecology within the WHO European Region, it is essential to have general advice on action to take when an invasive mosquito species has been recorded, or in the event of an outbreak of a mosquito-borne disease. The documents published by ECDC and WHO (ECDC, 2012; WHO, 2013b) are useful in this respect, although they offer only limited information on the steps needed to control an invasive species. The paucity of approved vector control tools may pose a problem for effective intervention, as most such tools depend on the use of chemicals which may not have been approved for use in mosquito control.

Harmonization of regulations between Member States at regional or subregional level is important and should be encouraged. An interministerial task force for vector control (see Section 6.2) could play a leading role in regional meetings leading to such harmonization.

6.2 Legislation

Rapid and effective vector control depends on legislation being in place that governs the operations needed for effective control; it should cover not only issues such as access to private property, water management, use of pesticides and public information, but also enforced action on public and private land to control invasive species. Such legislation is particularly important when vector control is needed at short notice – for example, when an outbreak of a serious VBD occurs (such as the outbreak of chikungunya that occurred in Italy in 2007).

Recent experience shows that introduction of invasive species is often associated with trade in imported used tyres and plants (Scholte et al., 2010); adequate control in these cases has sometimes been hampered by absence of appropriate legislation. This and other examples of accidental introduction of invasive mosquito vectors demonstrate the need for centralized action to bring in legislation that covers tools and/or chemicals recommended for vector control and elimination. The GVCR gives advice on how such an outcome can be achieved; in this, the proposed interministerial task force for vector control plays a crucial role. The task force should develop a rapid response tool (RRT) that can be applied when there are reports of invasive species that need to be eliminated or brought under control. The RRT should include tools to deal with larval and adult mosquito control, and have an approved protocol for use of biocides in accordance with EU and national regulations; it should also provide a reporting format so that actions taken are properly recorded, including reports of mosquito species identifications, densities and results of the control operation(s).

Some vector control tools depend on use of pesticides for which no regulation is in place. In EU Member States, use of pesticides has been regulated, but these regulations do not cover some of the pesticides required for mosquito control. The task force can be instrumental in resolving this issue so that, in case of an emergency, appropriate pesticides can be applied.

As many outbreaks of mosquito-borne disease are unexpected or cannot be anticipated with any great certainty, legislation should be in place that allows government authorities to take immediate action to control or eliminate an invasive mosquito species in such a way that further spread of the disease is halted.

6.3 Organization of vector control

The GVCR recommends that a national **interministerial task force for vector control** should be established, with representatives from all sectors of government and society associated with prevention and control of VBDs. For countries of the WHO European Region, the task force would be concerned more specifically with introduction, establishment and eventual control of invasive mosquito vectors. Such a task force should have authority to:

- ensure monitoring and surveillance;
- take measures that lead to a response following detection of an invasive species;
- ensure sufficient funding for actions needed;
- coordinate and regulate information made available to the public;
- liaise with health authorities in the event of an outbreak of a VBD;
- recommend actions that increase the likelihood of prevention and control of mosquito vectors; and
- strengthen training facilities in order to develop capacity for vector surveillance and control.

As some countries of the European Region are known to be endemic or highly receptive to native mosquito-borne infectious diseases (e.g. Greece, Turkey, Armenia, Azerbaijan, Georgia, Russian Federation, central Asian countries), the task force should also be charged with prevention and control of these diseases.

With the advice of the interministerial task force, countries can establish organized vector control, based on monitoring and surveillance of invasive mosquito species and/or endemic mosquito vectors. The GVCR emphasizes that a well-defined operational structure is fundamental to supporting systematic vector surveillance and to managing programmatic issues (WHO, 2017a). Such a structure can best be put in place by establishing a **vector monitoring and control centre** or unit led by experts in the ecology and control of mosquito-borne diseases. The GVCR provides a model to explain how such a centre should be organized and kept operational. Thus, for example, Pillar 3 of the GVCR describes how monitoring, surveillance and control can be organized and states which stakeholders should be involved, following a needs assessment led by the interministerial task force.

For historical reasons, technical expertise in vector monitoring, surveillance, control and evaluation has eroded in many countries. For this reason, the interministerial task force should pay specific attention to capacity-building at all levels. Staff to be employed in prevention and control of mosquito-borne diseases should be trained in entomology, ecology, vector control, surveillance, and management of geographical information and data.

One of the main tasks of the interministerial task force is to ensure that there is a preparedness plan for an outbreak of a VBD and the physical capacity to control and eliminate invasive mosquito species. Preparedness should be at all levels – administrative, technical, decision-making, etc. – and include guidance to staff on how to proceed in the event of an outbreak or discovery of an invasive mosquito species (see Section 5.6).

As VBDs may occur at any time, the task force should become a permanent body of expertise, with the capacity to ensure continuity of knowledge and data collection. For the task force's role in cross-border activities, see Section 6.5 below.

6.4 Administrative arrangements

Clear and concise protocols for the arrangement of a (national) centre for prevention and control of VBDs should be in place, as recommended in the GVCR, where emphasis is placed on the multisectoral aspect of vector control. The health ministry should have responsibility to take the lead in establishing and managing the centre, while other ministries are likely to be involved, including economic affairs, agriculture, public works, roads and transport, and tourism. In addition, nongovernmental organizations and industry may participate in vector control activities, as they too may be affected by outbreaks of VBDs.

Provision of adequate financial support for the activities of prevention and control of VBDs is required. The national task force can advise on the development of a budget that covers personnel costs, administrative support, and monitoring, surveillance and control operations.

6.5 Cross-border activities

VBDs are, by their nature, not limited to a single country. In many cases, an outbreak may rapidly cross borders and spread into neighbouring countries. In some cases, air traffic can also lead to accidental introductions.

In the event of an outbreak of a VBD or an invasive mosquito species being detected for the first time, countries should inform their nearest neighbours about this occurrence using available government channels. The interministerial task force on vector control could play an active role in this process – for example, by keeping up-to-date records of its contacts in neighbouring countries and by participating in regional and/or international meetings on early detection and prevention of VBDs.

7. Monitoring and evaluation

The presence, geographical distribution, population development and eventual establishment of an invasive mosquito species can go undetected if entomological monitoring is not routinely performed. In countries where mosquito-borne diseases such as West Nile virus, malaria and dengue are endemic, a centrally organized monitoring and evaluation service is usually present. In such countries, invasion of a new species is more likely to be detected than if no such service is available.

With global changes caused by environmental and climate change, and ever-expanding trade and travel (discussed in Section 1 above), the likelihood of exotic mosquito vectors invading new geographical areas is high, as the experience of the last decade has shown (Medlock et al., 2015). Once the presence of an invasive mosquito species has been confirmed, it is necessary to decide if further spread of the species should be halted, if elimination is feasible and desirable, and what actions should be taken to prevent the arrival and potential establishment of other mosquito vector species.

It is also possible that a route of invasion is discovered through which undesired species are routinely imported. For example, the trade in lucky bamboo plants, brought into the Netherlands from China, has led to very frequent importations of *Ae. albopictus* into the country (Scholte et al., 2008; 2010). Trade in used tyres has caused the invasion and successful establishment of *Ae. albopictus* in Italy, from where it has spread into much of southern Europe (Medlock et al., 2015). In some cases, the establishment or local presence of invasive mosquito species has already led to disease outbreaks, such as the chikungunya epidemics in Italy in 2007 and 2017 (Angelini et al., 2007; Venturi et al., 2017), and several cases of dengue associated with the presence of *Ae. albopictus* in France (La Ruche et al., 2010; Succo et al., 2016).

Mosquito species with known capacity as vectors of human pathogens, such as *Ae. vexans*, *An. sacharovi* and *Cx. pipiens pipiens*, are part of the endemic entomofauna of the European Region (see Section 2). Outside the European Region, or in selected parts of it, these species are known to transmit diseases such as Rift Valley fever *(Ae. vexans*), malaria (*An. sacharovi*) and West Nile virus (*Cx. pipiens pipiens*). Historically, *An. sacharovi* and several other members of the *An. maculipennis* complex that were endemic in Europe were responsible for transmission of much of the malaria that was highly endemic in Europe before the disease was eliminated from the Region (Bruce-Chwatt & de Zulueta, 1980). These anopheline species, however, are still present and could resume their role as malaria vectors if the parasite were imported from elsewhere, as happened in Azerbaijan, where more than 13 000 cases were recorded in 1996, with *An. sacharovi* as the principal vector. Also, in Greece, several cases of *Plasmodium vivax* have been recorded over a number of years, and these were associated with the presence of *An. sacharovi* (Danis et al., 2013). In 2017, autochthonous transmission of *Plasmodium falciparum* was detected in Ginosa, Italy. Turkey, which is one of the last countries of the European Region from which malaria was eliminated, remains vigilant to the danger of imported cases arriving from elsewhere (Ozbilgin et al., 2011). A monitoring and evaluation service therefore needs to include mosquito species that are already known to be efficient vectors of a human pathogen and which cause disease either locally or outside the Region.

7.1 Monitoring and evaluation as part of vector control

The organizational structure of vector control is described in Section 6. Appropriate vector control can only be planned and executed on the basis of data supplied by a monitoring and evaluation service. It is recommended that the interministerial task force for vector control (as described in Section 6) oversees and assumes responsibility for monitoring and evaluation of invasive mosquito vectors, as well as locally endemic ones, and makes arrangements for support and/or establishment of a monitoring and evaluation unit.

The monitoring and evaluation unit should operate from standard operating procedures which are developed with, and approved by, the interministerial task force, and it should report to the task force through a clear line of communication. In this way, early detection of an invasive species is most likely, and – if deemed necessary – control measures can be implemented as soon as possible.

7.2 Key indicators

The multiple purposes of monitoring and evaluation, in the context of prevention of establishment and control of vector mosquitoes, are:

- to account for resources used;
- to identify shortcomings and barriers;
- to measure impacts of operations; and
- to provide feedback to improve future decision-making.

To meet these objectives, monitoring and evaluation should measure inputs, outcomes and impacts of activities that contribute to prevention of establishment and control of vector mosquitoes. In a broad sense, these activities could include not only prevention and control operations, but also training courses, advocacy, institutional arrangements and policy development.

A functioning monitoring and evaluation system depends on a set of clear indicators for inputs, outcomes and impacts that can be objectively measured and used for comparison over time, between locations, and even between countries in the European Region. Such indicators help to determine whether activities are on track and whether they are achieving their anticipated impact.

Input (and process) indicators for individual vector control methods and strategies pertaining to each of the four scenarios have been discussed in Sections 4 and 5. These include items such as staff inputs, number of clean-up campaigns, response time, area covered, insecticide usage, frequency of trapping, frequency of operations, and level of participation of local authorities.

Outcome indicators include progress made in capacity-building; budget allocation for vector control; establishment of a national coordinating mechanism for vector control; and improvements made in raising awareness about the risks of vector mosquitoes among decision-makers and policy-makers. Impact indicators refer to the presence or density of vector mosquitoes and to the number of locally transmitted VBD cases.

Taking into account the four scenarios for vector control, a number of key indicators can be summarized, as presented in Box 3.

Box 3. Key indicators for vector control

Technical elements

- Type and number of traps used (ovitrap, adult trap)
- In case of larval collections: method of sampling (dipping, sieving, other)
- Species of vector mosquito
- Month of appearance or introduction of vector mosquitoes
- Vector control methods used
- Area covered by vector control
- Person days spent on vector control
- Susceptibility of targeted mosquitoes to available insecticides (level of resistance)
- Density of larval/pupal mosquitoes by species
- Density of adult mosquitoes by species

In case of local disease transmission

- Number of introduced and locally transmitted VBD cases
- Time from onset of illness to emergency response

Enabling factors

- Number of staff with job description referring to vector surveillance or control
- Interministerial task force on vector control in place
- National strategy or plan for control of vector mosquitoes in place
- Budget allocation for vector surveillance and control
- Outbreak preparedness plan ready to be activated
- Number of ongoing research studies on invasive mosquitoes or vector control

A plan for monitoring and evaluation should stipulate the roles, responsibilities, agreed indicators, targets, collection methods and reporting structure.

Discovery of an invasive mosquito species does not automatically require action – for instance, if it is a single, isolated event with no chance of spreading, no action is needed. However, in most cases detection of an invasive species is associated with further findings at several or many locations. In some cases, the invasive species has already become established before it is discovered (as was the case with *Ae. albopictus* in Italy in 1990 (Dalla Pozza & Majori, 1992)) or before adequate measures can be taken to eliminate the invader.

The most important indicators of a new mosquito species establishing itself are discovery of a larva, pupa or adult mosquito through description of morphological characteristics, to be followed, if possible, by molecular identification. (In this area, countries can assist each other by allowing use of their facilities when they are not otherwise available.)

Once the discovery of a new species has been confirmed, it is essential to establish if it is breeding and/or has become established, with a viable population. Monitoring and evaluation efforts should then be focused on reporting the population structure, population density and distribution of the new species.

It is important to establish the route along which the species may have arrived, and to determine whether this knowledge can be used to prevent further introductions and inform preventive measures.

In the event of a disease outbreak, national health authorities should be involved to establish the pathogen species, the size of the outbreak and the method of transmission. If importation is suspected, the origin of the pathogen and/or patient should, if possible, be established.

7.3 Reporting structure

Data collected through monitoring and evaluation should be regularly analysed, interpreted and documented; recommendations on new or modified activities or requirements should then be given. This information should be passed to the interministerial task force and its technical working groups, to assist them in reviewing progress and evaluating the effectiveness of interventions. The task force could identify specific information and recommendations that may need summarizing or “packaging” for different audiences, such as port authorities, local authorities, vector control teams, vector surveillance teams, regional decision-makers and national policy-makers.

As most countries in the WHO European Region have common borders with several countries, reports should be shared with neighbouring countries so that they are aware of developments concerning invasive mosquito species and actions taken by the country concerned.

7.4 Data management

Records of the occurrence of invasive mosquito species and associated disease outbreaks should be entered into a database stored at the national repository for health statistics and data. The data should be updated annually and evaluated by the interministerial task force.

Samples of vector species, as well as their associated pathogens and parasites, should be safeguarded in accordance with the appropriate academic standards. If stored at −80 °C, samples can later be subjected to molecular analysis for correct species identification and genetic information. This can assist in determining the country of origin of the invader as well as the pathogens and parasites encountered.

7.5 Mapping and geospatial data collection for development of surveillance protocols

Locations where invasive mosquito vectors are collected and/or have been found should be indicated with geospatial tools so that the geographical coordinates of the collection site are known to all concerned. This information is essential for assessment of the area of invasion, risk assessment of humans living near the site, and planning of interventions. Detailed information is available in a technical guide on surveillance of invasive mosquitoes (ECDC, 2012).

7.6 Monitoring of insecticide resistance and resistance management

Repeated or intensive use of insecticides to control vector mosquitoes or the diseases they transmit increases the selective pressure on vector populations to develop insecticide resistance. This represents a potential threat to the continued effectiveness of the available insecticides for vector control. Reports from various parts of the world suggest that *Ae. aegypti* can develop resistance to all available classes of chemical insecticides.

Wherever insecticides are used, the insecticide susceptibility of target species to the available products should be regularly tested (see *Global plan for insecticide resistance management in* *malaria vectors* (WHO, 2012b)). Monitoring changes in insecticide susceptibility involves taking samples from a number of fixed locations, or sentinel sites, that represent the at-risk areas or regions.

Susceptibility tests are simple bioassays in which live mosquitoes are exposed to a diagnostic dose of insecticide. The WHO bioassay is a standard test which uses test kits with filter papers and is available for adult mosquitoes (to test adulticides) and larval mosquitoes (to test larvicides). Bioassays provide quick results, but they are limited in that they cannot detect low levels of resistance or disclose the resistance mechanism.

Once insecticide resistance has been identified, a management plan including use of alternative insecticides as well as non-chemical tools should be considered (see Sections 4.1.1–3).

7.7 Data sharing with other countries

Mosquito vectors have a wide geospatial distribution, often covering many countries and even continents, and invasive species can rapidly cross borders. For this reason, it is of great importance that countries share data on mosquito distribution as well as information on invasive species. This allows early warnings to be given that lessen the threat of VBD outbreaks; it also means that the status of disease vectors (their presence and dynamics) can be continually updated.

A collaborative European network, VectorNet, coordinated by the ECDC, publishes and regularly updates distribution maps at country or local administrative level for a number of invasive *Aedes* species. The data are shared by participating experts from the respective countries. VectorNet also publishes surveillance maps showing the geographical coverage of currently known vector surveillance activities in countries that report to the ECDC (ECDC, 2018b). In addition to surveillance data, it is crucial that data on vector control and elimination are also shared and centrally managed (WHO/EMCA, 2013).

In support of data sharing, WHO issued a policy statement in the context of public health emergencies to ensure that decisions are based on the best available evidence (WHO, 2016b). The statement covers data sharing on surveillance, monitoring, emergency response and health facilities. As stated, WHO will disclose and publish information when the requirements for disclosure are satisfied, but will consult with countries before disclosing data, which will be anonymized.

8. Role of research

Vector surveillance and control depend on the availability of effective traps, larval sampling tools, geospatial tools, well-proven biocides, and personnel trained and skilled in working with mosquito vectors and their control. The control methods and tools are developed at universities, polytechnics and research institutions, which also play an important role in training of staff at all levels.

Polytechnics and universities, as well as national and international research institutes, conduct research on the biology, ecology and control of mosquito vectors and on the epidemiology and control of VBDs. For the purpose of surveillance and control of invasive mosquito vectors, the research community should be represented in the interministerial task force, where research will have an important role in providing guidance on the best methods of control.

New discoveries have often led to significant improvements in the efficacy of surveillance and control, and indeed VBD control. In recent decades, research in molecular biology and genetics has produced new and important information on mosquito taxonomy, leading to adjustments in our understanding of species distribution and disease risk. Technical advances in the scientific understanding of insect behaviour have led to new insights into mosquito behaviour when mating, host-seeking and searching for breeding sites. Advances in (bio)chemistry have led to the discovery of novel classes of insecticides, as well as tools for rapid assessment of insecticide resistance, which can be applied when preparing a resistance management plan (see Section 7.6). In addition, alternative tools for vector control are becoming increasingly available; these include the use of insect pathogens, push–pull systems (using attractants and repellents), genetic control such as Release of Insects carrying Dominant Lethals (RIDL) (Alphey et al., 2013), *Wolbachia*-based systems, and target-site delivery systems for biocides such as Bti (Takken and Knols, 2009).

The research community should be encouraged to share their discoveries and developments at an early stage with members of the VBD community, with a view to incorporating novel and effective tools as quickly as possible into existing control strategies.

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