

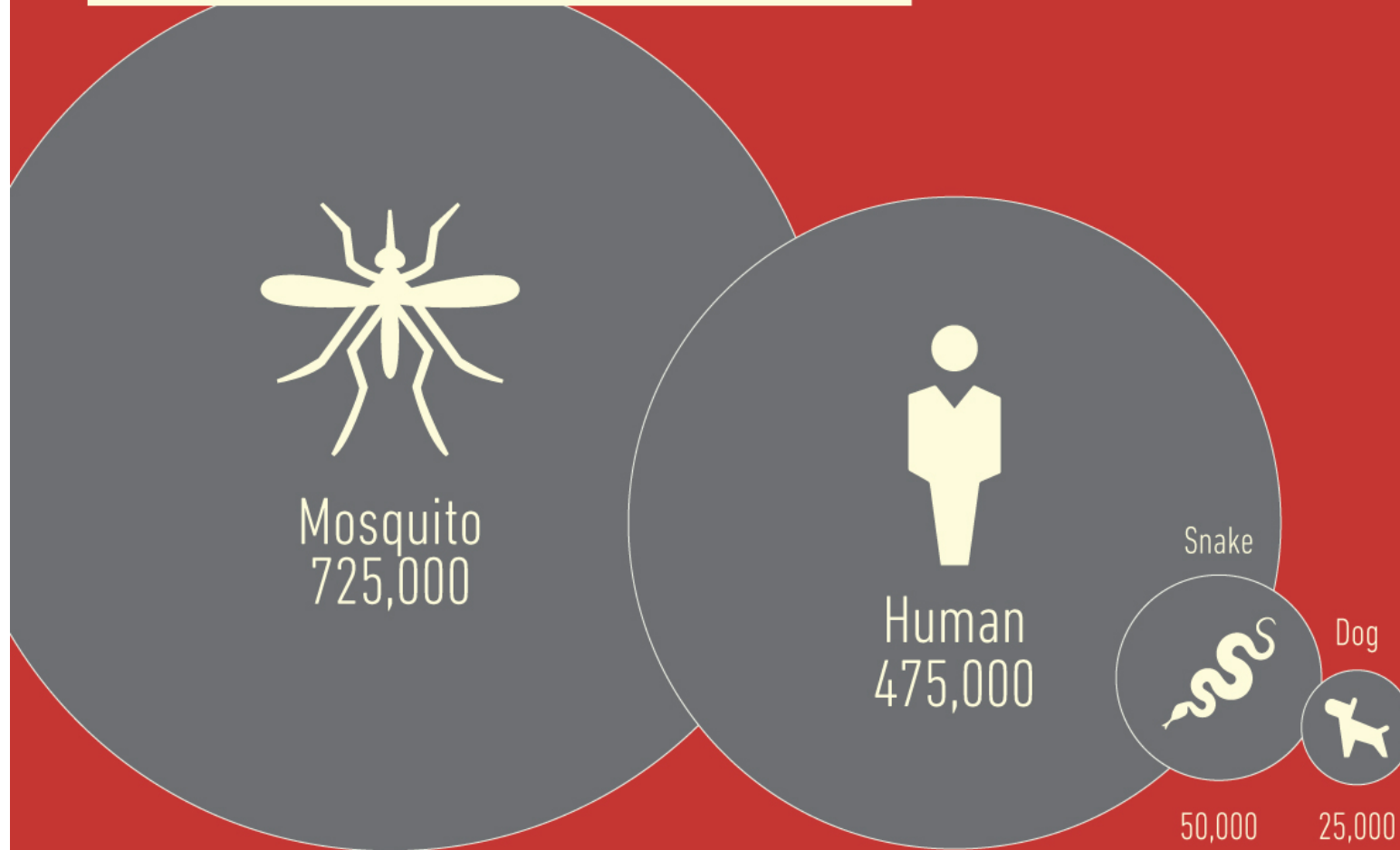
FYOS1001: Ecology of Infectious Diseases

Introduction to Mosquitoes as Vectors of Infectious Diseases

WHICH ANIMAL IS THE DEADLIEST?



NUMBER OF PEOPLE KILLED BY ANIMALS EVERY YEAR



Tsetse Fly



10,000

Assasin Bug



10,000

Freshwater Snail



10,000

Crocodile



1,000

Hippopotamus



500

Lion



100

Shark



10

Just one bite away from infection

Different species of mosquitoes can carry different diseases

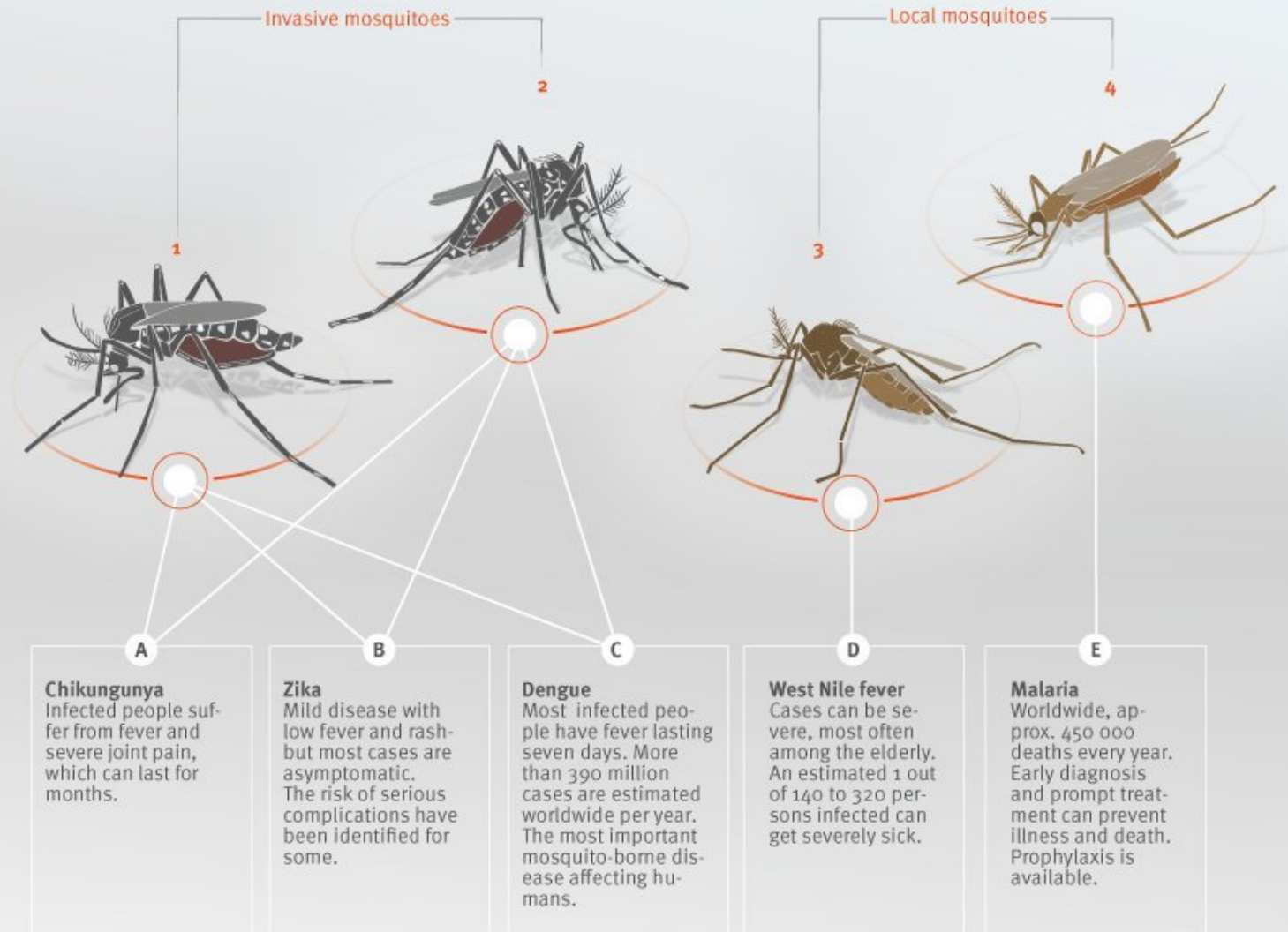
Invasive mosquitoes are characterised by their ability to colonise new territories. A considerable increase in the spread of invasive mosquitoes has been observed in Europe since the late 1990s.

1. After its disappearance in the 20th century in Europe, *Aedes aegypti* has recently become established in Madeira. It is also present in some areas around the Black Sea coast.

2. *Aedes albopictus* is considered to be the most invasive mosquito species in the world. It is present in much of southern Europe.

3. *Culex pipiens* is the most widespread mosquito in Europe.

4. The *Anopheles* mosquito can be found from south-eastern Sweden to Portugal.



ECDC, Stockholm, 2016.

To evaluate the risk of emerging vector-borne diseases to the EU, ECDC issues risk assessments on outbreaks occurring in Europe or EU overseas territories. ECDC collects environmental and climatic data through the E3 Network to support predicting the environmental suitability for vector-borne disease transmission in Europe. Jointly, EFSA and ECDC collect data on vectors and vector-borne diseases and analyse their spread in the European Union.

Mosquito-Borne Diseases Factsheet

Modified from the American Mosquito Control Association (AMCA)

Mosquitoes cause more human suffering than any other organism -- over one million people worldwide die from mosquito-borne diseases every year. Not only can mosquitoes carry diseases that afflict humans, they also transmit several diseases and parasites to dogs, horses, and birds. In addition, mosquito bites can cause severe skin irritation through an allergic reaction to the mosquito's saliva. Mosquito vectored diseases include protozoan diseases such as malaria, filarial diseases such as dog heartworm, and viruses such as dengue, encephalitis and yellow fever.

MALARIA

Malaria is an ancient disease. In all likelihood originating in Africa, it has been described by the Chinese as far back as 2700 BC and the Sumerians from 1700 BC. The malaria parasite (*Plasmodium* species) is transmitted by female *Anopheles* mosquitoes. The term *malaria* is attributed to Horace Walpole in a letter from Italy in 1740 and is derived from the Italian "mal-aria" or "bad air" because it was thought to come on the wind from swamps and rivers. Scientists conducted much research on the disease during the 1880s and early 1900s. Approximately 40% of the world's population is susceptible to malaria, mostly in the tropical and sub-tropical areas of the world. More than one million deaths and 300 - 500 million cases are still reported annually. Malaria was largely eradicated in temperate regions including the U.S. during the 20th century with the advent of DDT and other organochlorine and organophosphate mosquito control insecticides. An elevated standard of living, including the use of air conditioners and window screens, along with public health interventions have largely remanded malaria transmission to tropical areas. Nonetheless, it can still be found in northern Europe.

CHIKUNGUNYA

The name "Chikungunya" is attributed to the Kimakonde (a Mozambique dialect) word meaning "that which bends up", which describes the primary symptom – excruciating joint pain. Although rarely fatal, the symptoms are debilitating and may persist for several weeks. There is no vaccine and primary treatment is limited to pain medication. Recently chikungunya has established in the Caribbean (approximately 350,000 suspected cases in the Western Hemisphere since December 2013). It has now resulted in 2 cases of locally-transmitted Chikungunya virus in Florida in July of 2014. As of July 22, 2014, 497 travel-related cases have been found in 35 states, Puerto Rico and the U.S. Virgin Islands. The occurrence of locally-transmitted cases causes public health officials fear to its spread and establishment in states bordering the Caribbean. The mosquito species that transmit this disease are the Asian Tiger Mosquito (*Aedes albopictus*) and the Yellow Fever Mosquito (*Aedes aegypti*). Both species lay their eggs in containers such as cans, discarded tires and other items that hold water close to human habitation.

DOG HEARTWORM (*DIROFILARIA IMMITIS*)

Dog heartworm (*Dirofilaria immitis*) can be a life-threatening disease for canines. Dogs and occasionally cats, foxes and raccoons are infected from the bite of a mosquito carrying the worm larvae. Dog heartworm is dependent on both the mammal and the mosquito to fulfill its life cycle. The young worms (microfilariae) circulate in the blood stream of the dog. These worms must infect a mosquito in order to complete their lifecycle. Mosquitoes become infected when they bloodfeed on the sick dog. Once inside the mosquito, the microfilariae leave the gut of the mosquito and live in the body of the insect, where they develop for 2-3 weeks. After transforming twice in one mosquito, the third stage infective larvae move to the mosquito's mouthparts, where they will be able to infect an animal. When the mosquito blood feeds, the infective larvae are deposited on the surface of the victim's skin. The worms burrow into the skin through the wound caused by the mosquito bite, where they remain for 3-4 months. If the worms have infected an unsuitable host such as a human, the worms usually die. The disease in dogs cannot be eliminated but it can be controlled or prevented with pills or injections.

DENGUE

Dengue is a serious arboviral disease of the Americas, Asia and Africa. Although it has a low mortality, dengue has very uncomfortable symptoms and has become more serious, both in frequency and mortality, in recent years. *Aedes aegypti* and *Ae. albopictus* are the vectors of dengue. These mosquitoes prefer to lay their eggs in containers close to human habitations and are not well-controlled by standard spraying techniques. The spread of dengue throughout the world can be directly attributed to the proliferation and adaptation of these mosquitoes. There are four serotypes of dengue fever virus, and subsequent infections with different serotypes increase risk of developing deadly forms of the disease called dengue shock syndrome (DSS) and dengue hemorrhagic fever (DHF). This has made development of a vaccine highly problematic. Over the last 16 years dengue has become more common; for example, in south Texas 55 cases were reported in 1999, causing one death. More recently, Hawaii recorded 85 cases of dengue during 2001 and the Florida Keys reported over 20 cases in 2010. In 2004 Venezuela has reported more than 11,600 cases classic dengue fever and over 700 cases of dengue hemorrhagic fever (DHF), a deadly form of the disease. A recent outbreak in Indonesia caused more than 54,000 cases, of which 600 deaths.

YELLOW FEVER

Yellow fever, which has a 400-year history, at present occurs only in tropical areas of Africa and the Americas. It has both an urban and jungle cycle. It is a rare illness of travelers anymore because most countries have regulations and requirements for yellow fever vaccination that must be met prior to entering the country. Every year about 200,000 cases occur with 30,000 deaths in 33 countries; over the past decade, it has become more prevalent. In May 2003, 178 cases and 27 deaths caused by yellow fever were reported in southern Sudan. In the Americas 226 cases of jungle yellow fever have been reported with 99 deaths.

EASTERN EQUINE ENCEPHALITIS (EEE)

Eastern Equine Encephalitis (EEE) is spread to horses and humans by infected mosquitoes. It is among the most serious of a group of mosquito-borne arboviruses that can affect the central nervous system and cause severe complications and even death. EEE is found in freshwater hardwood swampland in the Atlantic and Gulf Coast states in the eastern part of North America, Central and South America, and the Caribbean. *Culex* species or *Culiseta melanura* mosquitoes feed on infected birds and become carriers of the disease and then feed on humans, horses and other mammals. EEE cannot be transmitted from humans or other mammals because the viremia presented in the disease is not sufficient to further transmission. Thus, humans and other animals are known as "dead-end hosts." Symptoms may range from none at all to a mild flu-like illness with fever, headache, and sore throat. More serious infections of the central nervous system lead to a sudden fever and severe headache followed quickly by seizures and coma. About half of these patients die from the disease. Of those who survive, many suffer permanent brain damage and require lifetime institutional care. There is no specific treatment. A vaccine is available for horses, but not humans.

ST. LOUIS ENCEPHALITIS (SLE)

St. Louis Encephalitis (SLE) is transmitted from birds to humans and other mammals by infected mosquitoes (mainly some *Culex* species). SLE is found throughout the United States, but most often along the Gulf of Mexico, especially Florida. Major SLE epidemics occurred in Florida in 1959, 1961, 1962, 1977, and 1990. The elderly and very young are more susceptible than those between 20 and 50. During the period 1964-1998 (35 years) a total of 4,478 confirmed cases of SLE were recorded in the United States. Symptoms are similar to those seen in EEE, and like EEE there is no vaccine for SLE. Mississippi's first case of St. Louis Encephalitis since 1994 was confirmed in June 2003. Previously the last outbreak of SLE in Mississippi was in 1975 with over 300 reported cases.

LACROSSE ENCEPHALITIS (LAC)

LaCrosse encephalitis (LAC) is much less widespread than EEE or SLE, but approximately 90 cases occur per year in all 13 states east of the Mississippi, particularly in the Appalachian region. It was reported first in 1963 in LaCrosse, Wisconsin and the vector is thought to be a specific type of woodland mosquito (*Aedes triseriatus*) called the tree-hole mosquito, which typically bloodfeeds on small mammals. Infrequent fatalities occur in children younger than 16. It is not transmissible from human to human. There is no vaccine for LaCrosse encephalitis.

WESTERN EQUINE ENCEPHALITIS (WEE)

Western Equine Encephalitis (WEE) was first recognized in 1930 in a horse in California. It is found west of the Mississippi including parts of Canada and Mexico. The primary vector is *Culex tarsalis* and birds are the most important vertebrate hosts with small mammals playing a minor role. Unlike LAC it is nonspecific in humans and since 1964 fewer than 1000 cases have been reported. As with EEE, a WEE vaccine is available for horses but not for humans.

WEST NILE VIRUS (WNV)

In 1937, West Nile virus (WNV) spread from Uganda into Europe, the Middle East, west and central Asia and associated islands. Serologically, it is a Japanese encephalitis virus antigenic complex similar to St. Louis, Japanese and Murray Valley encephalitis viruses. Similar to other encephalitises, it is cycled between birds and mosquitoes and transmitted to mammals (including horses) and man by infected mosquitoes. Mild WNV strains cause flu-like symptoms such as fever, headache, tiredness, body aches, and/or rashes. At least 63% of patients report symptoms lasting over 30 days, with the median being 60 days. More severe WNV strains can severely damage the nervous system and cause encephalitis or meningitis. WNV first appeared in North America in 1999 in New York with 62 confirmed cases and 7 human deaths. As of 2014, there have been 36,437 cases of WNV reported to the CDC. Of these, 15,774 have resulted in meningitis/encephalitis and 1,538 were fatal. The CDC estimates that there have been at least 1.5 million infections (82% are asymptomatic) and over 350,000 cases of West Nile Fever, but the disease is grossly under-reported due to its similarity to other viral infections.

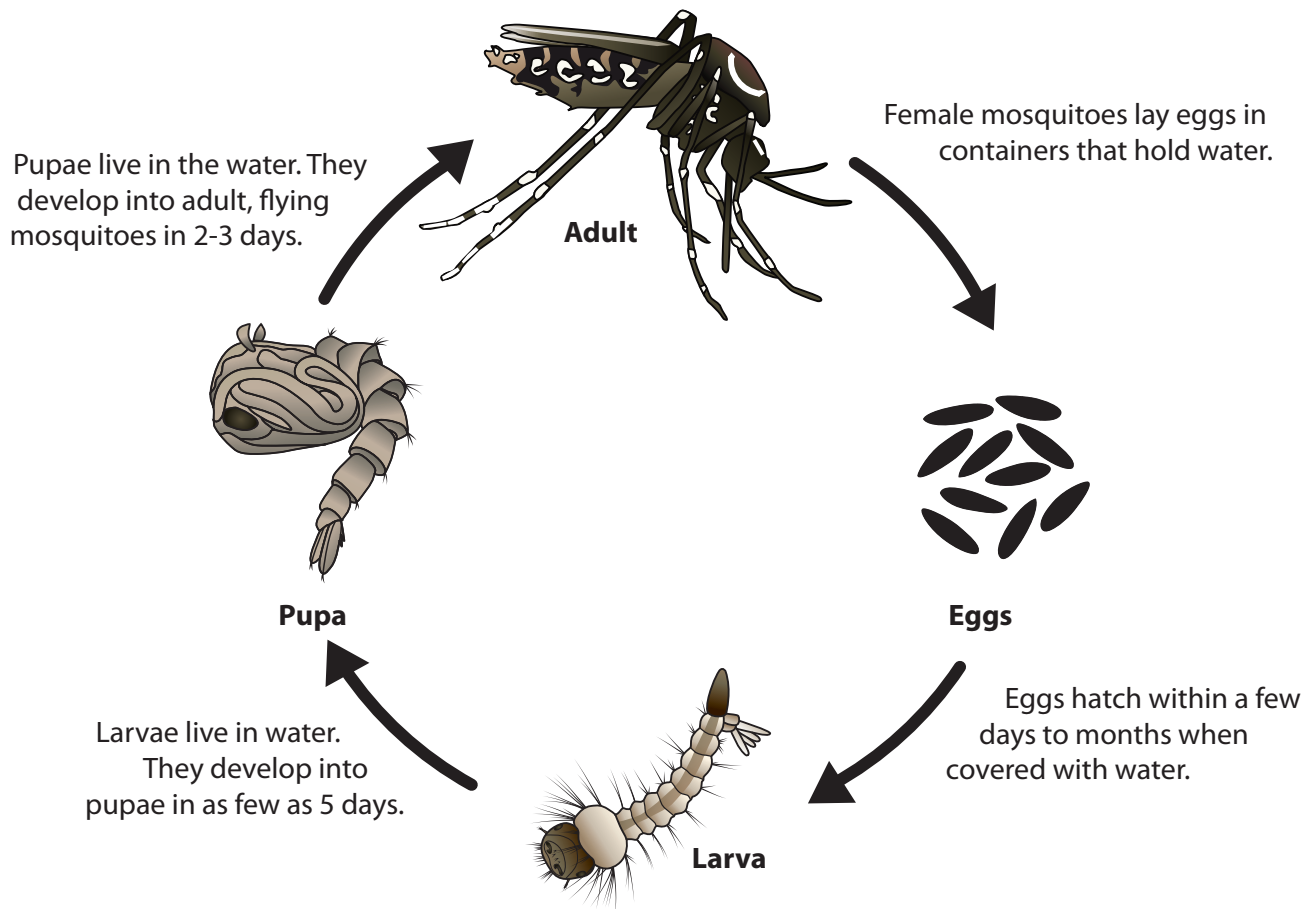
ZIKA VIRUS

Zika virus originated in central Africa but has spread to the South Pacific and western hemisphere. A Flavivirus related to West Nile, Yellow Fever, St Louis and the equine encephalitises, Zika was first discovered in macaque monkeys in 1947 in the Zika Forest region of Uganda. Since its discovery in 2014 off the coast of South America, Zika cases have been found in 35 countries in the Americas. As of 28 April 2016, there have been 426 reported cases of Zika virus in the U.S. due to travel to Zika-endemic areas. In US Territories in the Caribbean, a total of 599 cases have been reported, with 596 being locally acquired, primarily in Puerto Rico and the US Virgin Islands. Although in rare cases Zika can be spread through sexual contact with an infected person, it is usually transmitted through the bite of an infected *Aedes aegypti* or *Aedes albopictus* mosquito. Zika symptoms are typically mild and cold- or flu-like; often, patients are not sick enough to seek medical treatment, so a great many cases are not reported. However, cases of microcephaly, a congenital defect of cranium and brain size resulting in profound neurological defects in newborns usually resulting in death, have been positively identified as being caused by Zika infection. An autoimmune condition called Guillain-Barré syndrome, causing damage to nerve cells resulting in muscle weakness and, on occasion, paralysis and death, has also been linked to Zika infection.

Mosquito life cycle

Aedes aegypti

It takes about 7-10 days for an egg to develop into an adult mosquito.



Life stages of *Aedes aegypti* and *Aedes albopictus* mosquitoes

Eggs

- Adult, female mosquitoes lay eggs on the inner, wet walls of containers with water, above the waterline.
- Eggs stick to container walls like glue. They can survive drying out for up to 8 months. Mosquito eggs can even survive a winter in the southern United States.
- Mosquitoes only need a small amount of water to lay eggs. Bowls, cups, fountains, tires, barrels, vases, and any other container storing water make a great “nursery.”

Larva

- Larvae live in the water. They emerge from mosquito eggs. This happens when water (from rain or a sprinkler) covers the eggs.
- Larvae can be seen in the water. They are very active and are often called “wigglers.”

Pupa

- Pupae live in the water. An adult mosquito emerges from the pupa and flies away.

Adult

- Adult female mosquitoes bite people and animals. Mosquitoes need blood to produce eggs.
- After feeding, female mosquitoes look for water sources to lay eggs.
- *Aedes aegypti* and *Aedes albopictus* don't fly long distances. In its lifetime, a mosquito will only fly within a few blocks.
- *Aedes aegypti* mosquitoes prefer to live near and bite people.
- Because *Aedes albopictus* bite people and animals, they can live near homes or in neighboring woods.
- Mosquitoes live inside and outside.

For more information on diseases spread by mosquitoes:

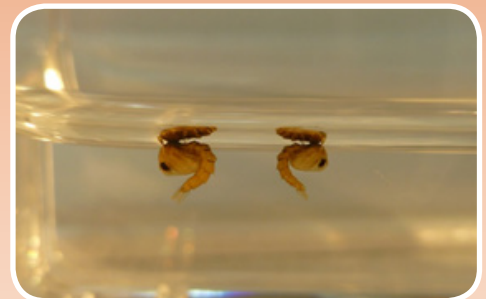
- www.cdc.gov/chikungunya
- www.cdc.gov/dengue
- www.cdc.gov/Zika



Eggs look like black dirt.



Larvae in the water.



Pupae in the water.

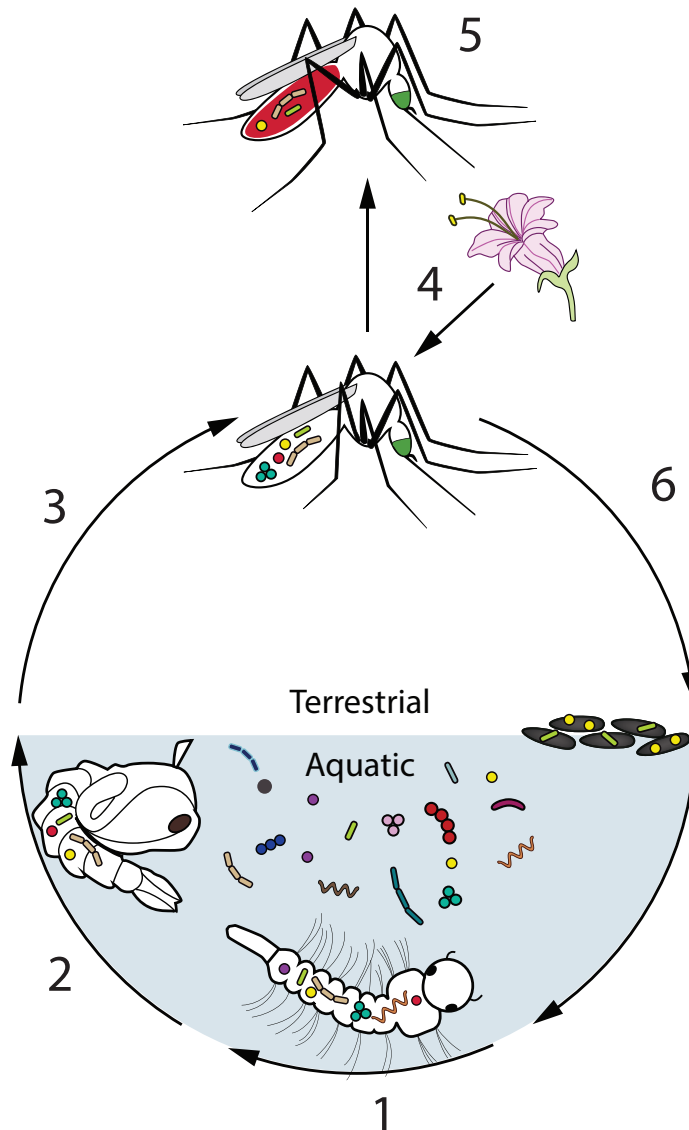


An adult mosquito emerges from a pupae.



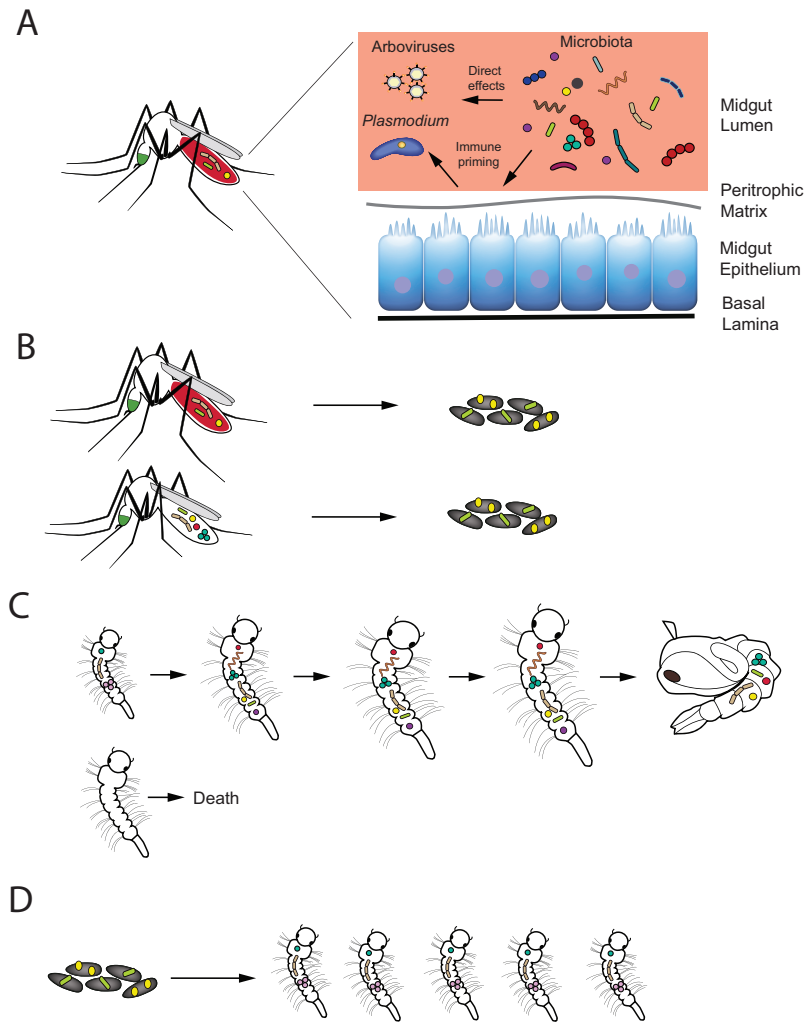
An adult mosquito bites a person.

Mosquitoes harbor many microbes that are neither vectored nor cause disease in vertebrates



Mosquito larvae ingest bacteria and other microbes in their aquatic habitat (1) that can be transmitted to pupae (2) and adults (3). Adults acquire bacteria by feeding on extrafloral nectaries (4). Blood feeding by adult females results in some gut community members increasing in abundance and other declining (5). Eggs females lay have some bacteria on their surface that are gut community members (6). Altogether these microbes form the mosquito microbiota.

The microbiota strongly affects several aspects of mosquito biology



Four main functional roles have been identified for the mosquito gut microbiota. A. Vector competency. To the left is an adult female after consuming a blood meal while to the right is a schematic of the midgut. The gut microbiota can negatively affect infection by some arboviruses and *Plasmodium* through direct production of factors or immune priming. The gut microbiota can also positively affect arbovirus infection. B. Nutrient acquisition and egg production. The gut microbiota in *Aedes aegypti* affects blood meal digestion and egg production. C. Larval development. Several mosquito species develop successfully with a gut microbiota but fail to develop beyond the first instar with no gut microbiota. D. Egg hatching. Bacteria on the surface affect egg hatching rates in *A. aegypti*.