MANAGING MOSQUITOES IN WASHINGTON IRRIGATED ORCHARDS

Mosquitoes and Disease

Mosquitoes can transmit pathogens that cause disease in humans, domestic animals, and wildlife (Stuchin et al. 2016). The burden of mosquito-borne disease lies mainly in the global tropics, but mosquitoes and disease-causing pathogens are present in the United States (Tolle 2009). One such pathogen, West Nile virus (WNV), arrived in the United States in 1999 (Montecino-Latorre and Barker 2018) and has since spread across the country (Reisen and Brault 2007).

Washington State is home to numerous mosquito species including those responsible for transmission of WNV (Sames et al. 2007). Irrigated cropping systems in Washington create suitable habitat for mosquitoes, and these insects and the viruses they transmit are concentrated in areas that use irrigation (Eisen et al. 2010; Crowder et al. 2013). In some areas of the state, nearly 15% of mosquitoes may be infected with WNV (Crowder et al. 2013). Abundance of mosquitoes in irrigated orchards may increase the risk of WNV for agricultural workers (Eisen et al. 2010; Crowder et al. 2013).

Mosquito Development

Mosquitoes develop through four stages: egg, larva, pupa, and adult. Adults live on land and feed on liquids from plants and fruits (Foster and Walker 2019). Blood, including human blood, provides adult females with a rich source of protein in order to produce viable eggs. Females lay eggs on the surface of water. The larval and pupal stages take place in the water where they develop until the adult mosquito emerges from the pupa. Egg, larval, and pupal development depend on temperature and food availability. Cooler water slows development of the immature mosquito, but when waters are warm during the summer months, development speeds up, leading to increased numbers of mosquitoes. Water with increased organic content will increase the rate of growth and speed up mosquito development (Foster and Walker 2019).

Mosquitoes of the genus *Culex* are the primary vectors of WNV. They prefer to lay their eggs in a variety of water sources, including but not limited to artificial containers like tires and buckets, storm drains, and wastewater treatment facilities (Rochlin et al. 2019). Some *Culex* mosquitoes prefer habitats associated with agricultural waters such as flood channels (Rochlin et al. 2019).

What Is West Nile Virus?

West Nile virus is the most commonly acquired mosquito-borne pathogen in the United States (CDC 2022). First introduced to the eastern United States in 1999, the virus rapidly spread to the West Coast by 2003 (Montecino-Latorre and Barker 2018). In the wild, WNV cycles between the mosquito and wild birds (Paré and Moore 2018). Mosquitoes acquire the virus by feeding on infected birds. Along with the nutritious blood meal, WNV present in the infected bird's blood enters the mosquito's digestive system. Once inside the mosquito, the virus reproduces and is transmitted during subsequent feeding events.

Who Is at Risk of Contracting West Nile Virus?

Humans and domesticated animals such as dogs, cats, and horses are at risk of contracting WNV and are known as "dead-end hosts" (Gould and Fikrig 2004; CDC 2022). Dead-end hosts are unable to transmit the virus back to a mosquito during feeding thus ending viral transmission (CDC 2022). Horses represent over 95% of WNV cases in domestic animals. The virus is associated with neurological disease in horses (Steyn et al. 2019). Fatality rates of 33% are reported, and 40% of horses that survive suffer prolonged or permanent neurological damage (American Association of Equine Practitioners 2022).

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A study in the northern Great Plains identified a higher risk for WNV in rural areas (Chuang et al. 2012). The study identified higher disease risk near wetlands and soils with high ponding frequency. Both environments provide habitat for mosquito development, and wetlands are ideal habitat for avian hosts (Chuang et al. 2012). Another study found the risk of WNV to be higher in counties across the Great Plains with high percentages of irrigated agriculture and large rural populations (Wimberly et al. 2008). Contrary to findings in the western United States, incidence of human WNV cases in northeastern regions is positively associated with urban land covers (Bowden et al. 2011). The positive association with agricultural land cover in the West can be explained by the geographic distribution of *Culex tarsalis*, the prominent vector of WNV in the western United States (Bowden et al. 2011).

Where Does the Virus Come From?

West Nile virus cycles between mosquitoes and birds, occasionally spreading to dead-end hosts like humans and horses. Over 65 mosquito species are known to harbor the virus (Colpitts et al. 2012). *Culex tarsalis* and *Culex pipiens* are the two major vectors of WNV in Washington State (Crowder et al 2013). Recently, *Culex salinarius* has been reported in multiple Washington counties and may also pose a threat to humans and animals due to its ability to vector the virus (Anderson et al. 2012; Petersen et al. 2017). West Nile virus has been identified in 250 known bird species, notably the American robin (*Turdus migratorius*), sparrows, and species in the crow family (Corvidae) (Colpitts et al. 2012; Riccetti et al. 2022). *Culex* mosquitoes prefer to feed on birds but will opportunistically take blood from other animals or humans (Riccetti et al. 2022). This opportunistic feeding behavior allows the virus to be spread between infected mosquitoes and non-avian hosts (Riccetti et al. 2022).

How Do Humans and Animals Get West Nile Virus?

West Nile virus is transmitted through the bites of mosquitoes. When a mosquito feeds, it probes the host in search of blood vessels (Colpitts et al. 2012). Simultaneously, the mosquito releases salivary secretions into the host to aid in the feeding process. The virus replicates within the salivary glands of infected mosquitoes and is released into the host with the saliva (Colpitts et al. 2012). *Culex* mosquitoes will opportunistically take blood from humans and domestic animals (Riccetti et al. 2022). If those mosquitoes have previously fed on infected birds, there is a change of WNV transmission to the new host (Riccetti et al. 2022). During certain times of the year, humans are more likely to encounter infected mosquitoes. In the United States, cases of WNV occur during warm months when mosquitoes are abundant with nearly 85% of cases of WNV occurring in August and September (Gould and Fikrig 2004).

Common Symptoms of West Nile Virus

The majority of those infected with WNV will not develop symptoms. Approximately 20% of humans infected with WNV will develop fever-like symptoms, and nearly 1 in 150 cases will be severe or fatal (CDC 2022). Common symptoms include headache, fever, neck stiffness, disorientation, paralysis, and muscle weakness; consult local medical professionals or the Centers for Disease Control and Prevention for a complete list of symptoms (CDC 2022).

Irrigation in Washington State

Washington State is home to diverse cropping systems with varying water requirements. The Cascade Range separates the wetter western side from arid eastern Washington. Annual rainfall in eastern Washington fails to meet the needs of some crops (WSU IAREC, n.d.). Irrigation is necessary to provide additional water to crops and orchards in much of the state, with nearly 1.8 million acres in Washington being irrigated (WSU IAREC, n.d.). Pivots, sprinklers, surface, and drip irrigation technologies are all available to meet water needs of the crop.

Central Washington is home to orchard crops such as apples, pears, and cherries. According to the United States Department of Agriculture (USDA), the term “orchard crop” is used to classify various crops grown in central Washington, including common stone fruits (cherries, peaches, nectarines, apricots, plums), pome fruits (apples and pears), grapes, and blueberries (Crowder et al. 2013). Each orchard crop has varying water requirements to maintain productivity and optimum yield (Brouwer and Heilbloem 1986). Irrigation is crucial for many central Washington orchard crops, and the water must be supplied to the orchards and stored prior to dispersal. The Columbia Basin Project was one of the largest irrigation projects completed under Congress’s 1902 Reclamation Act which focused on irrigating arid parts of the West (United States Bureau of Reclamation 2021). The Grand Coulee Dam, a concrete gravity dam located on the Columbia River west of Spokane, Washington, provides 330 miles of main canals and enough water to irrigate 680,000 acres (United States Bureau of Reclamation 2021). Water is funneled to growers from the Columbia River and frequently stored in holding ponds and reservoirs or tanks before it is pumped into an orchard's primary irrigation system.

Common irrigation methods in central Washington orchards include drip irrigation, micro-sprinklers, and under-tree impact sprinklers. The type of irrigation employed depends on numerous factors, including the type of crop, volume of water to be applied, age of the orchard and its layout, and cost of installing and maintaining the irrigation system (Peters et al., n.d.). Older orchards may have less efficient irrigation technologies since it is both expensive and impractical to update irrigation as new systems are developed. For example, overhead irrigation has become less common. The method of delivering water from above the tree or plant canopy may increase potential evaporation and incidence of foliar disease (Peters 2011). Instead of being a main source of water for trees, overhead irrigation has been repurposed as an integrated pest management strategy in pear and is now commonly used for washing sticky honeydew produced by pear psylla from pears (Brunner and Burts 1981). Overhead irrigation still exists in central Washington orchards, but more advanced systems like impact sprinklers and drip are frequently found in newer systems and replaced blocks.

Drip irrigation (Figure 1) offers the most precise water application at low pressure. This method can be easily automated and adjusted by growers depending on water requirements. Water drips slowly from emitters to the plant roots. The slow drip decreases incidence of plant disease caused by water splashing on foliage, reduces water loss via evaporation, and lessens water applied to weeds or unprofitable drive rows (Peters 2011). Micro-sprinklers (Figure 2) placed between trees or bushes cover a small area and thus have high application efficiency and are ideal for orchards with slopes or irregular block shapes, potentially saving up to 30% of water (Godin and Broner 2013). Impact sprinklers (Figure 3) use two rotary sprinklers to push water in a circular pattern. Impact sprinklers apply water more broadly, so this method has less precise water placement than both drip and micro-sprinkler methods. Leaky pipes, broken sprinklers, or damaged drip lines may cause undesirable water pooling or puddling throughout an orchard. Systems should be operated under correct pressures and regularly monitored and maintained to optimize function.

Figure 1. Drip irrigation in apples at Washington State University's Sunrise Research Orchard. (Photo: L.E. Flandermeyer.)

Figure 2. Micro-sprinkler in sweet cherry block at Washington State University's Sunrise Research Orchard. (Photo: L.E. Flandermeyer.)

Figure 3. Impact sprinkler at Washington State University's Tree Fruit Research and Extension Center. (Photo: L.E. Flandermeyer.)

How Does Irrigated Land Provide Mosquito Habitat?

Water is crucial for productive growth in orchards; however, supplying too much water may generate suitable habitat for mosquitoes. In central Washington, the massive water influx via irrigation canals creates larval mosquito habitats. Ponds, reservoirs, and channels used to hold irrigation water can create ideal habitats for mosquito eggs, larvae, and pupae. Holding ponds provide habitats for wildlife. Growers in Othello, Washington, noted the presence of large mammals, insects (including mosquitoes), and amphibians in holding ponds utilized to irrigate central pivot land (Riley Reed, personal communication). The presence of vegetation around ponds and canals further increases wildlife abundance, including mosquitoes. For example, the invasive Russian olive tree (*Elaeagnus angustifolia*) is prevalent in irrigated lands of the Pacific Northwest (Gunn and Patterson 2021) and creates habitats for mosquitoes (Friesen and Johnson 2013). Aquatic vegetation slows the flow of water through canals creating stagnant pools—ideal mosquito habitats (Antonelli et al. 2007).

In natural water bodies, fish may consume immature mosquitoes and limit their adult numbers, but in irrigation networks fish are intentionally excluded (United States Bureau of Reclamation 2006). Irrigation systems in disrepair may provide additional habitats in orchards. Leaks cause water to pool and create permanent and semipermanent puddles in which mosquitoes can develop (Chuang et al. 2012). Tire ruts from vehicles or central pivot systems can hold enough water for mosquitoes to develop (Jamieson et al. 1994). This is problematic when puddles form near fruit trees where mosquitoes can be shaded from the sun, find sugar sources from plants, and feed on birds and workers.

Why Does Irrigation Management Matter for Mosquito Control?

Culex mosquitoes are known vectors of WNV in Washington State. Controlling mosquito populations is crucial to reduce disease presence and spread. Steps should be taken to identify, reduce, and prevent the creation of mosquito habitats across orchards. In fields with large mosquito populations, working conditions are poor. Anecdotally, worker strikes have occurred in orchards with severe mosquito problems (Adrian Marshall, personal communication). Even with protective clothing, workers still suffer bites and extreme nuisance from mosquitoes. Irrigation practices should be evaluated and properly maintained to reduce potential mosquito habitat. It is equally important to control water usage to satisfy the requirements of an orchard and its drive row. Using too much water for irrigation may lead to soft soils and pooling as well as misappropriation of water resources. Reduction in water usage saves money on water and pumping costs while reducing potential mosquito habitats, preventing excess growth of weeds, and reducing costs associated with insect and weed control (Lawler and Lanzaro 2005).

Mosquito Control

Source reduction. By eliminating the habitat of immature mosquitoes, the number of biting adults will be reduced (Becker et al. 2010). In an agricultural setting, the following source reduction strategies can be used:

- Keep irrigation lines in repair to ensure there are no leaks which may form standing water.
- Remove water-holding containers, such as discarded tires and buckets.
- Ensure proper drainage of fields by eliminating water-retaining, low-lying areas in the terrain. This includes adjusting field levels and filling in puddles and tire ruts with soil or gravel (Lawler and Lanzaro 2005).
- Remove debris and vegetation in irrigation channels to ensure water flows through rapidly. Mosquito larvae are unable to survive in fast flowing water (Antonelli et al. 2007).

Personal protective measures. Despite implementing adequate controls, it is impossible to eliminate all mosquitoes from the environment. Thus, personal protection is an important component in controlling the bites of mosquitoes (Becker et al. 2010). Ways to protect yourself include (the below information is based on research and does not represent instructions by a licensed pesticide applicator):

- Wearing long sleeves and pants that minimize exposed skin.
- Using Environmental Protection Agency and Washington State Department of Agriculture registered insect repellents according to label.
- Avoiding the outdoors during times of day when mosquitoes are most active. *Culex* spp. are active during twilight and nighttime hours.

DEET—a synthetic active ingredient in many insect repellents. Look for products with 10–35% DEET (Katz et al. 2008; California Department of Public Health 2023).

Picaridin (KBR 3023)—a synthetic active ingredient that is highly effective against mosquitoes (Katz et al. 2008; California Department of Public Health 2023).

Ethyl butylacetylaminopropionate (IR3535)—a synthetic active ingredient in insect repellents that is moderately effective (WHO 2005; California Department of Public Health 2023).

Oil of lemon eucalyptus (OLE)—a naturally derived active ingredient from the lemon eucalyptus plant. Concentrations of 10–30% are effective (Katz et al. 2008).

Permethrin—a contact insecticide and repellent applied to clothing in low concentrations that can reduce the risk of mosquito bites (Katz et al. 2008; California Department of Public Health 2023).

Chemical controls. Adult and larval mosquitoes may be effectively controlled by chemical methods. Always use pesticides according to the label and consult with federal, state, and local agencies when necessary. The [Pesticide Information Center OnLine (PICOL) Database] hosted by Washington State University's Pesticide Resources and Education Program is a free, searchable tool containing Washington's registered pesticide labels.

Adulticides can effectively control terrestrial, adult mosquitoes when used according to the label. These insecticides are not for use in water. Permethrin, pyrethrins, malathion, and naled are active ingredients in common insecticides used for adult mosquito control (Washington State Department of Ecology 2004). Adulticides are available as ultra-low volume aerial sprays and as residual treatments on vegetation and other surfaces where adult mosquitoes rest (Amoo et al. 2008; Bonds 2012). Selective larvicides are used to control larval forms of mosquitoes in water. Application of any aquatic pesticide (including private applications) in Washington requires a license through the Washington State Department of Agriculture (WSDA) with either an aquatic pest control or public health pest control pesticide license category and a Clean Water Act (NPDES) permit from the Washington Department of Ecology (Washington State Department of Ecology 2004).

- Methoprene is an insect growth regulator that prevents larval maturation (Washington State Department of Ecology 2004).
- Monomolecular surface films control larvae and pupae by interfering with mosquito breathing (Washington State Department of Ecology 2004).

Biological controls. Predatory fish may be introduced into water sources with no surface inlet or outlet to control mosquitoes (Washington State Department of Ecology 2004). Stocking fish in native waters requires a permit from the Washington State Department of Fish and Wildlife (WDFW). Seek guidance from WDFW prior to introducing new species whether they are native or not. Certain non-native fish species are not permitted as they are aggressive towards native fish and wildlife or cause severe ecological impacts (Washington State Department of Ecology 2004).

- *Bacillus thuringiensis israelensis* (Bti) and *Bacillus sphaericus* (H-5a5b) are bacterial agents that target the larval digestive system (Washington State Department of Ecology 2004).
- Western mosquitofish (*Gambusia affinis*) are small, non-native, warm water fish known to drastically reduce mosquito larvae in shallow waters (Washington State Department of Ecology 2004). Mosquitofish require a permit from WDFW and should not be the sole strategy for mosquito abatement.
- Three-spined stickleback (*Gasterosteus aculeatus*) are native to Washington and prey on mosquito larvae (Washington State Department of Ecology 2004).

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