Guide for public health units: Considerations for adult mosquito control
Public Health Ontario

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Executive Summary

During the summer of 2012, Ontario experienced the second highest number of West Nile Virus (WNV) human cases and positive mosquito pools since WNV was first identified in Ontario in 2002. This was accompanied by increased interest from the public and media. While no public health unit (PHU) initiated an adulticiding program, PHUs identified the need for more insight into the factors that affect WNV activity in Ontario, especially those that can assist in determining whether or not to adulticide.

In late 2012, a working group made up of representatives from PHUs, the Ministry of the Environment, the Ministry of Health and Long-Term Care, and Public Health Ontario was formed to develop a document that would outline a range of factors that PHUs should consider when evaluating whether or not adulticiding during the WNV season would reduce the risk of exposure to WNV infected mosquitoes.

This document is intended for WNV prevention and control and not nuisance-mosquito control programs. The document is not intended to be directive but aims to provide general scientific information to help inform the decision to adulticide, which remains with the local medical officer of health (MOH). Adulticiding is just one of the tools that a PHU can use to try to reduce the risk of WNV illness in humans. Other important components of a comprehensive WNV program that PHUs employ are mosquito and human surveillance, source reduction, larviciding, and public education (i.e. personal protective measures).

During its deliberations several themes became clear to the working group:

- Ontario has never adulticided for WNV.
- No specific indicators, or WNV activity levels, have been identified in Ontario that reliably indicates the need for adulticiding.
- While human WNV cases may drive the decision to adulticide, they are reported closer to the end of the mosquito season and PHUs may not realize maximum benefits from initiating the adulticiding process at that time of year since the vast majority of human cases would already have occurred.
- The decision to adulticide will be based on a variety of imperfect surveillance data sources which include indicators of historical risk of transmission (human case counts), indicators of current risk of transmission (positive mosquito pools), and indicators of the potential for the ongoing risk of future transmission (weather and mosquito life cycle considerations). The decision to adulticide can only prevent WNV transmission events that are anticipated to occur at least one week after a decision to adulticide is taken.
Background

PHUs conduct WNV human and mosquito surveillance to inform decisions concerning their WNV programs, including public education and mosquito control. In rare circumstances, adulticiding may be considered as an extra mosquito control measure to prevent WNV illness. The decision to adulticide will have significant implications, including the public’s health, financial costs, public communications and public perceptions. These implications make it important that the decision to adulticide is based on knowledgeable and timely interpretation of the best available data. There is no simple trigger or threshold that PHUs can use to inform their decision to adulticide. Attempting to predict the level of WNV activity in any upcoming season is not currently feasible.

As with other illnesses, the incubation period, health care-seeking behavior of cases, laboratory testing, and public health reporting timelines mean that case counts rarely reflect the true burden of illness at any given point in time. Environmental factors create additional complexity when anticipating the level of risk and when making risk-mitigation decisions for reducing WNV illness. The decision to adulticide must evaluate the potential burden of illness, taking into account a variety of available surveillance data (e.g., mosquito surveillance, human disease, environmental) to gauge the potential risk of WNV illness to humans.

Mosquitoes and Seasonality

Ontario’s mosquito surveillance program primarily monitors Culex pipiens/restuans populations, as they are the primary vector(s) responsible for human cases in the province. Ontario’s two highest years for WNV-positive mosquito pools and human cases were 2002 and 2012.

On average, the number of positive pools peaks in mid- to late August (Figure 1). The peak can shift a couple weeks earlier or later depending on environmental factors (e.g., temperature) that may increase or decrease the level of WNV in the mosquitoes that year.

In years with relatively high WNV activity (e.g., 2012), the number of C. pipiens/restuans and the percent that are WNV positive will be higher at least a couple of weeks earlier than the historical average. In years where PHUs are observing these early increases in mosquitoes, they may have the possibility of having a higher-than-average number of human cases. PHUs may want to look at these factors and consider taking control actions (e.g., larviciding, source reduction, public education) before human cases either appear or start to increase.

Culex pipiens/restuans’ life cycle

Mosquito species in Ontario have different ways of overwintering (surviving during the winter). Some will overwinter as eggs, while others will stay in their larval form. For Cx. pipiens/restuans, the last generation of adult females will not take a blood meal and will go into diapause (overwintering). This change in adult blood-feeding behavior is influenced during their larval stage by temperature and the number of daylight hours and usually occurs around mid-August. During years with above average temperatures, this overwintering behavior can be pushed back to later in the season. In Canada, Cx.
Figure 1. The approximate generations of adult Culex mosquitoes throughout the season (adapted from Wood et al. \(^1\)). There is a gap in June, as it takes time for the mosquitoes to develop into adults from the eggs laid by the overwintering generation. The average number of WNV-positive mosquito pools, percent positive *Cx. pipiens/restuans* pools and accumulated degree days for Ontario were calculated using mosquito testing and trapping data from 2002–12. The average number of probable and confirmed WNV human cases was calculated for each week across all years from 2002–12 based on onset date and reported date. The estimated time of exposure, calculated as 15 days prior to symptom onset, is Vector Index Formula:
pipiens/restuans usually have overlapping generations (Figure 1), with the first being the overwintering females and the next generation occurring between mid-June and the end of July. The third generation usually occurs from the end of July to beginning of September. The last generation of adults typically begins to emerge at the beginning of September. Therefore, when considering adulticiding, it is important to target the second and third generations, as these include individuals seeking another blood-meal. These second and third generations will still be biting at the end of August and up to the beginning of September, depending on the weather. Since they are older, these females have had a chance to take more than one blood meal and are more likely to have acquired WNV. PHUs that observe the typical mid-August peak of human cases may not realize maximum benefits from initiating the adulticiding process at that time of year since public notification and operational considerations would mean that actual adulticiding would only be possible at the end of August by which point the vast majority of transmission events would already have occurred and remaining mosquitoes would typically be entering diapause (see predicted human exposure period in Figure 1).

Vector index

Ontario’s mosquito surveillance program collects data on the species of mosquito captured, the approximate number of each species identified, and the number of positive mosquito pools. The vector index (VI) combines all three of these factors to give a comprehensive estimate of the potential number of infectious mosquitoes.

\[ VI = \sum_{i=\text{species}} N_i \times P_i \]

\( N \) = average number of mosquitoes per trap, \( P \) = estimated infection rate

The VI gives the estimated number of infected mosquitoes per night and can be calculated for individual species or combined species to give an overall assessment of risk at the level of an individual trap or for the entire PHU. Once the VI has been calculated, it can be compared to previous weeks and years to give an overall trend of what the viral activity is in the mosquito population. Each PHU calculates its own historical VI values and uses them as a comparison group to help interpret the current year’s data when developing thresholds. The VI can be calculated for individual weeks, but should also be observed over consecutive weeks to determine if there is an increasing trend. In Ontario, the VI will primarily be calculated for Cx. pipiens/restuans as this is the main vector of importance for WNV in the province. Additionally, Cx. pipiens/restuans is the vector predominately tested for WNV (and targeted by surveillance methods); therefore, we have a more robust data set associated with it compared to other vector species. Refer to Nasci et al. 2005 for good examples of how VI is used based on maximum incubation period. Weekly ADD values are based on 18.3°C for southern Ontario. Weather stations south of North Bay were used for this analysis.

The VI can then be used to assist in determining the risk of human cases, as it typically increases before the human cases are diagnosed and become visible to public health though this temporal pattern of increasing VI preceding diagnosed cases may not be evident every WNV season. While VI may help to determine the level of WNV activity in some PHUs, it may not work for all of them as it will depend on the numbers of mosquitoes being captured and the prevalence of WNV. Some PHUs may have low vector counts or a small sample size, which may make the VI result less reliable. PHUs should also take into consideration the number of traps they are using and how they are distributed in their region. No
clear level—at which the VI could reliably indicate the need for adulticiding—has been identified in Ontario or elsewhere.

**Accumulated degree days (ADD)**

A degree day occurs when the average temperature for a single day (24 hours) is 1°C above a reference temperature. For Ontario, this temperature is 18.3 °C for *Cx. pipiens/restuans* (F. Hunter, personal communication)\(^5\). Therefore, if the average temperature for a day was 19.3 °C, then one degree day would be accumulated. If the average temperature for a day reached 25.3°C then the degree days accumulated for that day would be 7. ADDs are the continuous addition of consecutive degree days from a set starting point. Public Health Ontario (PHO) uses an internal database that pulls the daily weather data from Environment Canada’s website and then calculates the ADD for the requested week.

Higher temperatures suggest that mosquitoes will be going through their life cycles more quickly and that the virus will also be amplifying faster in the mosquitoes. Therefore, seasons with higher ADD earlier in the season tend to have a higher risk of WNV-positive mosquitoes and human cases. On average, over the last 11 years, Ontario sees its first human cases between 100 and 125 ADD, with double-digit numbers of human cases appearing around the 180-200 ADD mark (Figure 1). Positive mosquito pools can occur as early as 30 ADD, with double-digit numbers of positive mosquito pools above 140 ADD (Figure 1). PHUs may want to look at their own local trends and determine their own local patterns when making risk assessments. Comparing averages to the current year, and years with high WNV activity, may assist in gauging the severity of the current year (Figures 2-4).

During a year with high WNV activity, it is also important to monitor the weather forecasts for the upcoming weeks, as this will help to predict how the temperatures may influence mosquito and virus replication and ultimately whether WNV mosquito activity will continue to increase, stabilize, or decrease. If the forecast predicts that the weather will stay relatively warm and it is the middle of the season (weeks 28-32), then it can be expected that WNV mosquito activity will continue to increase. Cool temperature forecasts might mitigate other risk indicators such as a high or rising vector index.

**Human cases**

On average, human cases start to occur at the beginning of July and peak at the end of August based on symptom onset dates (Figure 1). Due to incubation periods, health care-seeking behaviour, and diagnostic timelines, these cases typically only become visible to public health three or more weeks after the transmission event occurs (Figure 1). These reporting timelines mean that adulticiding decisions based solely on human cases may not be timely enough to prevent the peak number of transmission events. In 2012, the human cases started to appear approximately two weeks ahead of the average peak time (Figure 3). Adulticiding at or just prior to the peak mosquito transmission period is expected to have the greatest public health impact in terms of human cases averted.

PHUs should look at the various factors to see how they correlate with their own human case data. Increased media coverage may cause more people to seek testing and health care providers to request testing. This may cause an increase in total cases but a decline in the proportion of severe cases as there are more people getting tested. Hospitalized and/or neurological cases, can give a more accurate
Figure 2. Ontario average number of positive mosquito pools, by week, from 2002–12 versus the years 2002 and 2012. Note the relatively early and rapid increase in the number of positive mosquito pools in 2002 and 2012 when the highest numbers of human WNV cases were recorded in Ontario.
Figure 3. Ontario average for 2002-12 for the number of positive human cases, by week, versus the years 2002 and 2012.
Figure 4. Ontario average for the number of accumulated degree days (ADD), by week, from 2002–12 versus the years 2002 and 2012. Note the early rapid rise in ADD and the sustained rapid increase of ADD into early September in 2002 and 2012 creating the conditions for sustained rapid vector and viral replication throughout the seasons with the highest human case counts.
assessment of the current season, as their prevalence will probably not be as easily influenced by changes in public perception and health care testing.

While adulticiding interventions target mosquitoes, the number of human cases, their location, and the severity of infections (i.e., neurological cases) will have a strong influence on considering to adulticide.

As of 2012, Ontario has yet to adulticide based on its levels of human WNV activity. It is anticipated that, regardless of mosquito activity, PHUs would require significant numbers of human cases before considering adulticiding. Furthermore, consideration of adulticiding should only occur after other control methods have been explored (e.g., consideration of an additional round larviciding, public education).

**Adulticiding Window**

One of the main aspects to consider is timing of adulticiding in relation to future anticipated WNV activity. Depending on the severity of the season, it would be ideal to conduct the spraying before, or during, the peaks in human transmission events (e.g., increasing positive mosquito pools, vector index, significant human case counts). Peaks in WNV human transmission activity tend to occur around the middle of August (Figure 1). Indications of current WNV activity should be supported by ADD, predicted weather in the coming 1-2 weeks, and temporal data that suggest that significant human transmission activity will continue for several weeks. Once the decision to adulticide has been made, it will likely take a week or more of preparation and public notification before the actual spraying begins. It should also be noted that it may take more than one night of spraying to cover the targeted area; and the area may need multiple treatments. Given the time to adulticide, it is important to consider if the intervention will be done at a time when WNV activity in the environment is still having a health impact to warrant its use.

Malathion is the only mosquito adulticiding product registered for use in Ontario. For information on this product and its use, refer to the most current version of the *WNV Preparedness and Prevention Plan.* Additional information can be found at:

Discussion

The multifactorial nature of quantifying WNV risk and the relatively short experience Ontario has had with WNV, means making a decision to adulticide is not straightforward. In a year where PHUs are considering adulticiding, PHO is available to provide scientific and technical assistance to MOHs to determine the appropriate course of action to reduce the risk of WNV in their jurisdictions.

The local MOH holds responsibility for deciding whether or not to adulticide in their PHU. During a season when adulticiding may be necessary, the targeting of adulticiding within a PHU contributes an additional level of complexity to the decision-making process. Specific areas to target within a health unit will vary by season, and, of course, will be informed by the best available surveillance data. Mosquito trap locations, case residential addresses, and locations where cases were exposed may not overlap completely and could create decision-making challenges of their own. The where and when of adulticiding will have to consider maximizing impacts on vector populations, while providing the most benefit to the public: reduced numbers of human cases and illnesses. Since its introduction into the province, Ontario has not adulticided for WNV vectors. Currently, there is no set of scientifically validated Ontario triggers to indicate when and where adulticiding is warranted. The material presented here has been summarized in order to help ensure that a robust interpretation of the biological and environmental data is considered in any decision to adulticide.

Developing a predictive model is dependent on having sufficient volumes of data from multiple years with high levels of WNV activity. Ontario has had WNV for 11 years, but only two years with high levels of WNV activity (2002 and 2012). Currently, there is no model that works reliably for Ontario and there is very little data with which to try to generate a model; however, as Ontario continues to have WNV, the generation and testing of predictive models will continue. PHO is collaborating with York University to investigate the feasibility of a WNV predictive risk model for Ontario that could aid in the decision-making process surrounding adulticiding. PHO will continue to work with PHUs and partners to attempt to determine what indicators work best for predicting a WNV season and which ones will provide the best information for making decisions regarding the need for adulticiding.


4. Nasci RS, Doyle M, Biggerstaff BJ, LeBailly A. Calculation and application of a vector index (VI) reflecting the number of WN virus infected mosquitoes in a population. Poster presented at: 71st Annual Meeting of the American Mosquito Control Association. 2005 Apr 3-7; Vancouver BC.


communications:
Fiona F. Hunter. Professor: Biology. Brock University, St. Catharines, Ontario