Evaluation of Pennsylvania's Mosquito-Borne Disease Control Program and Future Directions

by

Georgie Scott

BS Biology, Delaware Valley University, 2015

Submitted to the Graduate Faculty of

the Department of Infectious Diseases and Microbiology

Graduate School of Public Health in partial fulfillment

of the requirements for the degree of

Master of Public Health

University of Pittsburgh

2019

UNIVERSITY OF PITTSBURGH

GRADUATE SCHOOL OF PUBLIC HEALTH

This essay is submitted

by

Georgie Scott

on

August 5th, 2019

and approved by

Essay Advisor:
Mackey R Friedman, PhD, MPH
Assistant Professor
Infectious Diseases and Microbiology
Graduate School of Public Health
University of Pittsburgh

Essay Readers:

Elizabeth M Felter, DrPH
Assistant Professor
Behavioral and Community Health Sciences
Graduate School of Public Health
University of Pittsburgh

Leah Lamonte, MS
Vector Control Specialist
Vector Control Program
Allegheny County Health Department
Pittsburgh, Pennsylvania

Mackey R Friedman, PhD, MPH

Evaluation of Pennsylvania's
Mosquito-Borne Disease Control Program and Future Directions

Georgie Lillian Scott, MPH

University of Pittsburgh, 2019

Abstract

Introduction: Since the introduction of West Nile Virus (WNV) to the United States, there has been a need to monitor the mosquito populations that act as vectors. Programs such as the Pennsylvania Mosquito-Borne Disease Control Program (MBDC) were founded to combat the ever-growing threat to public health. By using various methods of surveillance, control, and educating the public, the population size of mosquitoes that can transmit WNV to humans can be reduced.

Question: What is the effectiveness of treating catch basins to control mosquito populations?

Methods: A literature search was conducted to ascertain the current research findings pertaining to catch basin treatment, to gauge the effectiveness of this intervention. The articles collected were systematically reviewed against inclusion criteria, and further analyzed for key findings and common ideas.

Results: A total of eight articles met the criteria for inclusion. These were thoroughly examined in order to determine effectiveness and relevance of catch basin treatment to control endemic mosquito populations. It was found that the treatment of catch basins is effective and other factors such as type of treatment form such as granular or briquet and cost should be considered.

Discussion: The MBDC program includes methods that are recommended in order to control mosquitoes and protect the public from mosquito-borne disease such as West Nile Virus. This review suggests that it is effective and should be implemented in other counties in Pennsylvania. The evidence supports the current program in Allegheny County, which can serve as a model for programs statewide. Suggested modifications to the program include use of granular formulations of larvicides over briquets. Other factors can aid in incorporation of this integrated management approach, such as rolling the events into education opportunities.

Table of Contents

List of Tables

List of Figures

Preface

All pictures not otherwise cited were taken by the author. I want to take the chance to thank the members of my committee, and all the people who aided me throughout my academic pursuits. It was a long road, and I would not be here without all your help. Thank you.

1.0 Introduction

West Nile Virus (WNV) is a flavivirus transmitted by arthropods (arbovirus) that was first discovered in the West Nile district of Uganda in 1937 [1]. In the years following this discovery, the virus continued to slowly disseminate outside the African continent causing outbreaks in Western Europe and India. In the mid-to-late 1990s the virus was identified as the cause of outbreaks of meningitis and encephalitis in adults in Romania and other Eastern European countries. The spread continued as the virus was found across the Atlantic. It was first identified in the United States in 1999 in New York, and within 3 years spread across the country [2]. This was concerning, as the virus carries the risk of being neuroinvasive in some cases. From 1999-2018 there were a total of 50,830 reported cases of WNV, and 24,656 neuroinvasive cases across the United States [3]. The virus was found in Pennsylvania in 2000, and since then has developed a program to monitor the mosquito vectors to control the virus's spread [4].

The Mosquito-borne Disease Control Program (MBDCP) in Pennsylvania primarily focuses on West Nile Virus (WNV). The Pennsylvania Department of Environmental Protection (DEP), Department of Health (DOH) and Pennsylvania Department of Agriculture (PDA) collaborated to develop a program to track and control viral outbreaks. The DEP funds several counties in the state annually to carry out this program on the local level (Figure 1.1) [1]. It originally was developed to control just WNV, but later evolved to include surveillance methods for those mosquitoes that carry other viruses such as Zika and Chikungunya. These are also arboviruses belonging to the same family as WNV [5]. The overall mission of the program according to the manual is as follows:

"The mission of the Mosquito-borne Disease Control Program (MBD) is to reduce expected morbidity and mortality, health care costs, and the financial impact that these disease outbreaks would have upon Commonwealth industries such as agriculture, fishing, hunting, tourism, etc. This mission is accomplished through an integrated mosquito management (IMM) program consisting of education, surveillance, and control of mosquitoes."

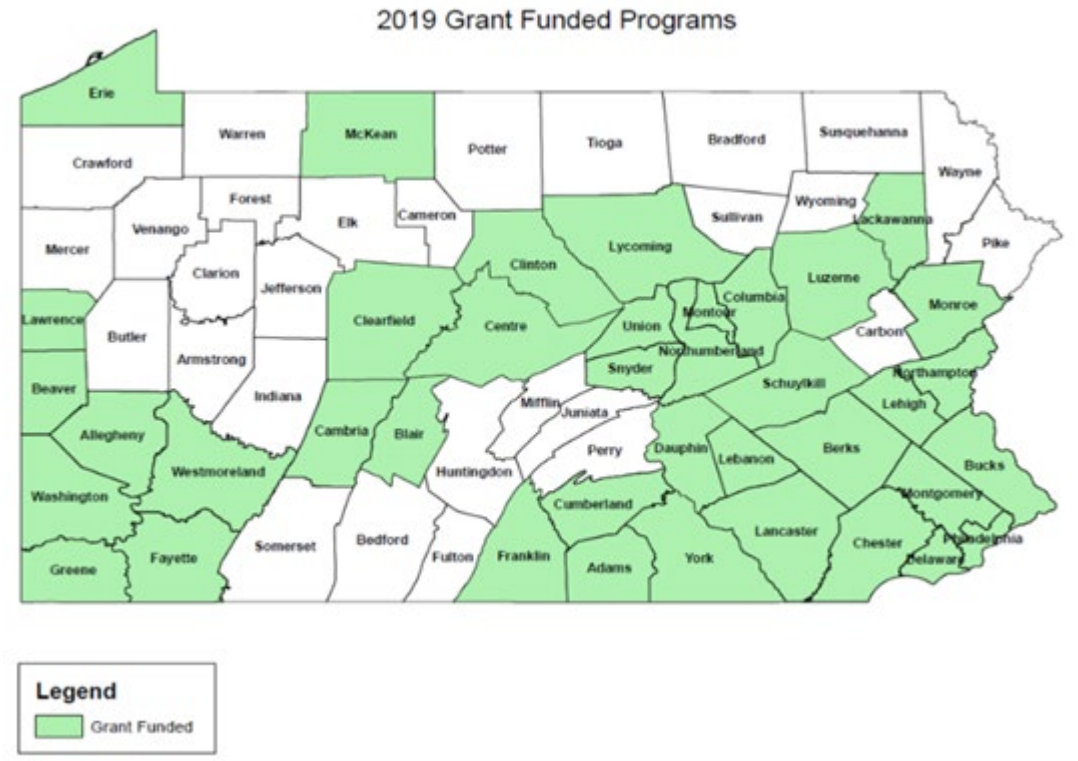


Figure 1.1 Current locations of the Mosquito-Borne Disease Control Grant in Pennsylvania.

1.1 West Nile Virus

This virus is in the family *Flaviviridae* along with other disease-causing pathogens such as Dengue, Zika, and Japanese encephalitis viruses. The virus is a positive single-stranded RNA virus that is about 50 nm in size with a genome of 11 kilobases. These form roughly 10 coding regions for proteins, 3 of which are for structural proteins and the other 7 are nonstructural to be used for replication. The life cycle for the virus consists of 4 stages, attachment/entry, translation, replication, and egress. WNV enters its target cells by binding to specific cell-surface protein receptors, although the precise receptors are currently unknown. There are potential receptors being considered such as DC-SIGN and Integrin $\alpha_v\beta_3$, which may vary between cell type as WNV can infect more than one cell type. Once WNV attaches to its target cell, it enters via cell-mediated endocytosis in which the acidification of the endosome causes the conformational change that allows for the release of the viral nucleocapsid into the cytoplasm. The virus' genome is translated and processed. Once this occurs the newly transcribed genomes are then packed into the new virions which will mature and use the ER-Golgi complex to eventually be released from the cell by exocytosis [6].

The virus is most commonly spread through the bite of an infected mosquito. The mosquitoes, commonly belonging to the *Culex* genus, become infected from birds carrying the virus. This is the normal cycle for the virus, but the mosquitoes can feed on other organisms such as horses or humans (Figure 1.2). These are what are known as "dead-end hosts", because these particular species cannot transmit the virus back to the mosquito to continue the infection due to the normally low viremia in the hosts [6]. Though this mode of transmission is by far the most common there have been reports of blood transfusions and organ donations resulting in infection

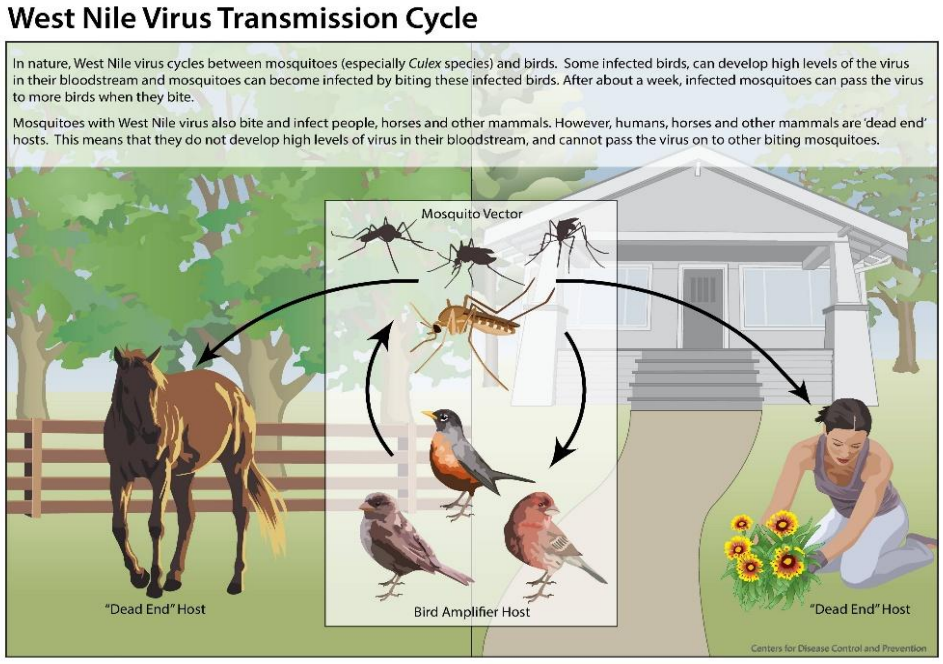
as well as vertical and perinatal transmission. The clinical symptoms of WNV disease vary greatly from person to person. A majority of people infected, around 80% according to the CDC, show no signs of any symptoms [7]. Those with symptomatic infections typically experience febrile illness along with headaches, nausea, vomiting and sometimes a brief rash that can be found on the trunk, arms or legs of the patient. This lasts for less than seven days, but some can still feel a sense of fatigue during recovery. The main concern lies with those symptomatic patients who experience the neuroinvasive form of the disease. This accounts for roughly 5% of patients. Symptoms of this form of infection include encephalitis and meningitis which are characterized by headaches, light sensitivity, confusion, and fever. In addition to these symptoms, the patient can suffer from poliomyelitis-like symptoms such as asymmetric weakness. Further testing via an IgM antibody-specific ELISA performed on serum taken 8-21 days post display of symptoms is recommended to rule out other conditions such as a stroke or Guillain-Barre Syndrome [6]. There is no vaccine or antiviral treatment available for humans, but there is a vaccine for horses [7].

1.2 Mosquito Species

The main concern of this program is with those mosquitoes endemic to Pennsylvania from the *Culex* genus and, in the case of nuisance abatement, the Asian tiger mosquito or *Aedes albopictus* (Table 1.1). *Culex pipiens*, also known as the Northern house mosquito is a light brown mosquito (Figure 1.3). They do not have distinctive markings on their proboscis or legs, which can make them difficult to differentiate from other *Culex spp.* The females can be

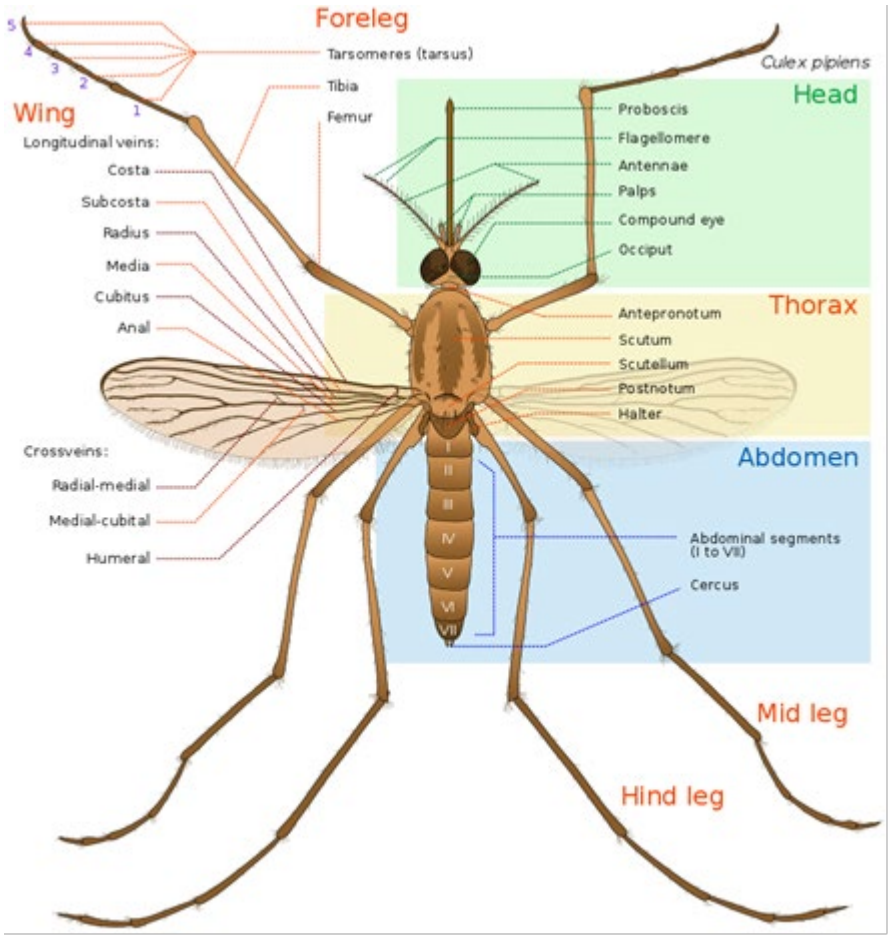
identified morphologically by their unique pale abdominal banding. The larvae can be identified by a long siphon with anywhere from 6-13 pecten teeth on the basal 1/3. There are normally 4 branched tufts on the siphon, and one is normally out of alignment with the other three [8]. *Culex restuans* shares many characteristics with *Cx. pipiens*, but its larvae can be mistaken for *Aedes spp.* when collected due to their short antennae and body structure. By using a microscope, it can be seen that these larvae typically have single hairs on their siphons which is unique to *Cx. restuans* in the northeastern United States [9]. *Aedes albopictus* adults are identified by their black scaling with white bands. They also have a distinct silver scales that form a stripe on the dorsal side of the thorax and head [10].

The biting patterns of these species are all different. Both *Culex spp.* do get blood meals from birds and mammals, but *Cx. restuans* is far more likely to bite birds over people or other mammals [8; 9]. The Asian Tiger mosquitoes are aggressive day biters hence their status as a nuisance, but it should be noted that they are competent vectors for diseases such as Dengue virus which could lead to more opportunities for the spread of the disease to new locations in the future [10]. What these species all have in common are their breeding habitats. The females seek out standing, organic water for egg laying. *Aedes spp.* have a tendency to avoid very polluted water, while *Culex* has not been noted to be averse to any potential habitat. These water sources can be in larger habitats like grassy swampland or pools, but can also include catch basins, small containers, buckets, and tires [8-10].



Courtesy of the Centers for Disease Control and Prevention (CDC)

Figure 1.2 WNV transmission cycle



Courtesy of Wikimedia Commons

Figure 1.3 **A diagram of *Culex pipiens***

Table 1.1 A list consisting of the most mosquito common species in Pennsylvania

MOSQUITO SPECIES AND BIOLOGY

COMMON MOSQUITO SPECIES IN PENNSYLVANIA

Of the 62 species of mosquitoes in Pennsylvania, the following are the most commonly collected in gravid, host-seeking traps and dipping samples.

Species	Characteristics	Larval Habitat	Seasonality	Disease Transmission in PA	Trap
Aedes albopictus	Small, black and white color patterns, aggressive daytime mammal biter	Artificial containers, bird baths, rain gutters, tarps, bottle caps, garbage bins, fast-food containers, houseplant containers, scrap yards	June-October	Zika, WNV, Chikungunya (Highly efficient vector)	Gravid, BG, Light
Aedes vexans	Brown with small pale bands on legs, opportunistic mammal and bird biter	Floodwater, retention areas, woodland pools, ruts, ditches	April-October	WNV (Efficient vector)	BG, Light
Anopheles punctipennis	Pale spots on wings, long palps, aggressive large mammal biter	Clean water, wetlands, ponds, ruts, tires, diverse habitats	April-October	WNV (Inefficient vector)	BG, Light
Anopheles quadrimaculatus	Lack of pale spot on wing, long palps, aggressive large mammal biter	Clean water, wetlands, ponds, ruts, tires, diverse habitats	April-October	None	BG, Light
Coquillettidia perturbans	Large, pale bands on legs, aggressive mammal biter	Wetlands especially with cattails	June-October	WNV (Inefficient vector)	BG, Light
Culiseta melanura	Curved, dark proboscis	Swamps, flood water, wood land pools	May-October	EEE (Efficient vector)	Resting boxes
Culex erraticus	Small, dark blackish mosquito, opportunistic mammal and bird biter	Ponds, wetlands	May-October	None	Gravid, BG, Light
Culex pipiens	Brown, mostly a bird biter, main vector in WNV cycle	Polluted water, artificial containers, STPs, tires, retention areas, ruts	June-October	WNV (Highly efficient vector)	Gravid, BG and Light later in the season
Culex restuans	Brown, mostly a bird biter, main vector in WNV cycle	Artificial containers, STPs, tires, retention areas, ruts, catchbasins, woodland pools, ubiquitous	April-August	WNV (Highly efficient vector)	Gravid

MOSQUITO SPECIES AND BIOLOGY

COMMON MOSQUITO SPECIES IN PENNSYLVANIA

Of the 62 species of mosquitoes in Pennsylvania, the following are the most commonly collected in gravid, host-seeking traps and dipping samples.

Species	Characteristics	Larval Habitat	Seasonality	Disease Transmission in PA	Trap
Aedes albopictus	Small, black and white color patterns, aggressive daytime mammal biter	Artificial containers, bird baths, rain gutters, tarps, bottle caps, garbage bins, fast-food containers, houseplant containers, scrap yards	June-October	Zika, WNV, Chikungunya (Highly efficient vector)	Gravid, BG, Light
Aedes vexans	Brown with small pale bands on legs, opportunistic mammal and bird biter	Floodwater, retention areas, woodland pools, ruts, ditches	April-October	WNV (Efficient vector)	BG, Light
Anopheles punctipennis	Pale spots on wings, long palps, aggressive large mammal biter	Clean water, wetlands, ponds, ruts, tires, diverse habitats	April-October	WNV (Inefficient vector)	BG, Light
Anopheles quadrimaculatus	Lack of pale spot on wing, long palps, aggressive large mammal biter	Clean water, wetlands, ponds, ruts, tires, diverse habitats	April-October	None	BG, Light
Coquillettidia perturbans	Large, pale bands on legs, aggressive mammal biter	Wetlands especially with cattails	June-October	WNV (Inefficient vector)	BG, Light
Culiseta melanura	Curved, dark proboscis	Swamps, flood water, wood land pools	May-October	EEE (Efficient vector)	Resting boxes
Culex erraticus	Small, dark blackish mosquito, opportunistic mammal and bird biter	Ponds, wetlands	May-October	None	Gravid, BG, Light
Culex pipiens	Brown, mostly a bird biter, main vector in WNV cycle	Polluted water, artificial containers, STPs, tires, retention areas, ruts	June-October	WNV (Highly efficient vector)	Gravid, BG and Light later in the season
Culex restuans	Brown, mostly a bird biter, main vector in WNV cycle	Artificial containers, STPs, tires, retention areas, ruts, catchbasins, woodland pools, ubiquitous	April-August	WNV (Highly efficient vector)	Gravid

From the Mosquito-Borne Disease Control Program Manual, characteristics detail life cycle, biting patterns as well as roles played in the WNV life cycle if applicable. Note the Disease transmission column. This column shows the vector efficiency of mosquitoes for particular diseases.

1.3 Mosquito Surveillance

In order to track WNV presence in Pennsylvania, mosquito surveillance is the main method employed by this program. In order to collect data on the local populations, a variety of methods are used. Larvae and pupae are collected in standing water via dipping, a common method of obtaining counts of these life stages [1]. This involves locating a habitat that would be attractive to mosquitoes for breeding. Mosquito habitats include areas with standing, organic water such as storm drains and sewage treatment plants (Figure 1.4). In order to obtain a sample, a scoop is dipped into the water and the number of mosquitoes at these life stages are counted. Sampling of these areas is meant to be done through the most active breeding times during the year, which is typically April through October. Samples will then be used to find the density of larvae and pupae in the area (average number of specimens per dip).

Another main trapping method that is detailed in the MBDC guide includes the use of gravid traps (Figure 1.5). Gravid is in reference to the female mosquitoes that have had a blood meal and are carrying eggs. Traps are placed at fixed sites weekly during the entirety of the season. This is done to have points of comparison for future seasons. Sites are chosen due to the history of their populations, reported cases of illness and habitat types. Surveillance can be increased if mosquito-borne disease is detected in the area of a site. Gravid traps act as lures. The organic stagnant water in the trap pan is an attractive habitat to lay eggs for the female mosquitoes (Figure 1.6). Once they land, they are pulled into the trap collection chamber to be sorted and shipped later (Figures 1.7, 1.8). This is to be used as a baseline because they have already consumed a blood meal that could potentially be infected. Due to *Culex spp.* being active during evening and morning hours, traps are set midday and collected the following morning.

The final trap type is known as a host-seeking trap. These traps are designed to attract blood-seeking mosquitoes. BG Sentinel or BGS traps are used for collecting *Aedes spp.* such as *A. albopictus*. BGS traps work well for these species of mosquitoes due to the trap's black and white color scheme, the human lure and the use of dry ice to mimic CO_2 being released in an exhale (Figure 1.9). These are set for 24 hours in order to collect mosquitoes with different biting patterns. Another option for collecting host-seeking data is landing rate counts. The collector observes the number of mosquitoes landing on them for a set period [1].

This provides a breeding ground for *Culex* mosquitoes as well as other species that do not mind more turbid conditions.

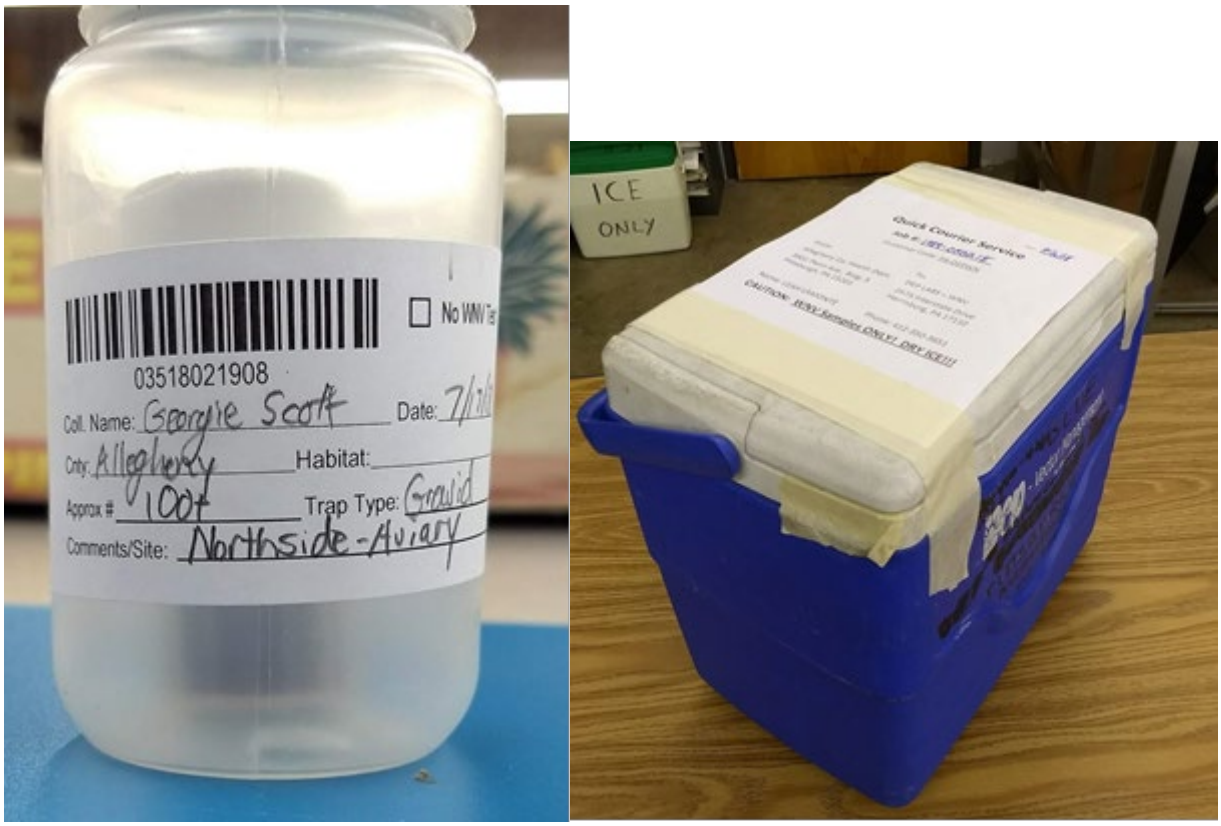
Figure 1.4 A catch basin containing standing organic water

Figure 1.5 Gravid traps in fixed site locations

This mix of dry grass clippings or hay, roughly 40 gallons of water and around ¼ -½ (~150 mg) dipper of lactalbumin creates an organic mix that is an ideal habitat for mosquito larvae.

Figure 1.6 The lure used in gravid traps, aptly named "stink water”

Figure 1.7 Collection chamber containing mosquitoes and other insects trapped during the 20 hour period



The adults are sorted after being knocked down on dry ice. They are placed into a scintillation vial, then into a larger container (125 mL). Larval and adult samples are given a number to identify them by called an USI number. The data collected from surveillance efforts should be entered prior to shipping. The system will be updated with the positive or negative status of the samples.

Figure 1.8 A specimen jar (left) containing sorted mosquitoes from a fixed trap site. The shipping cooler (right) is packed with dry ice and shipped overnight to ensure the sample arrives with the virus if it is present, still intact

Note the dry ice container placed above the fan acting as a lure for mosquitoes seeking a blood meal. Due to *Aedes spp*. in Pennsylvania being active day biters this acts as someone exhaling and leaving a trail for the mosquitoes to follow.

Figure 1.9 A BG trap in operation

1.3.1 Dead Bird Surveillance

The influence of birds on the levels of WNV is significant because birds are the reservoir for the virus [1]. Their role in the amplification cycle of the disease over the season and their following migration pattern leads to more infected mosquitoes that are then left without their preferred food source. They will turn to other species such as humans. Dead bird surveillance activities are included in many grant-funded programs. Many bird species are affected by WNV infections, but corvids and raptors are particularly vulnerable. Corvid is another name for those birds from the family *Corvidae* which includes ravens and magpies. Raptors are birds of prey such as hawks. Reports of dead birds by the local community can help provide insight to the WNV levels.

When a resident calls the local health department or authority in charge of mosquito control about a dead bird the following protocol is recommended for that authority [1].

1. If the bird has been deceased for less than 48 hours it is to be placed on ice. The resident can then bring the bird to the office or have it picked up to be orally swabbed. The swab is placed into a scintillation vial, then into a 125 mL bottle. The bottle is then labeled with a "bird label" which includes the county and bird information. This can then be shipped to the DEP with the weekly mosquito samples.
2. In the case of the bird being dead for longer than 48 hours or it is not known how long it has been deceased, it is best to dispose of the animal in the garbage. Carcasses with sunken eyes, maggots or ants are far more

difficult to diagnose for WNV levels than those that are more recently deceased.

3. If the caller has difficulty describing what the bird is i.e. “black” or “large”, use previous knowledge of that area to determine if it is worth testing the animal.

According to the MBDC Manual, it is recommended to take action once there have been at least five (5) reports of dead wild birds (pigeons are excluded). In this case, the first point of contact is the local PA game commission office. If the bird does not fall under the normal category (e.g., is not a raptor or corvid), the commission will decide if it has the capacity to swab the bird [1].

1.3.2 Education

Outreach and education by those conducting the mosquito control efforts can aid in reducing mosquito populations and reduce risk of infection for the residents [1]. The MBDC guide places an emphasis on providing up to date information and accessibility to local efforts. Another major point that is addressed is public awareness of the issue of container-breeding mosquitoes such as *Aedes albopictus*, an invasive species that became established in Pennsylvania in the past ten years. These mosquitoes have not been shown to be vectors for infectious diseases affecting humans in Pennsylvania as of 2019 but are classified as nuisance mosquitoes. Educating homeowners about this species can help engage them as well as hopefully reduce habitats for *A. albopictus*. Target demographics that are mentioned for WNV prevention are the general public with an emphasis on seniors, doctors, and animal owners. Media outlets are included as well as

local governmental bodies. Ways of engaging these populations include presentations to local organizations such as schools. Other ways to reach out are attending health fairs, radio and television interviews, partnerships with other local agencies, social media, newspaper articles, and building relationships with local boroughs and townships (Figure 1.10).

The Allegheny County Health and Safety Fair is one example of an opportunity to educate the public about WNV risk as well as other vector-borne diseases such as Lyme.

Figure 1.10 An example of an outreach event

1.4 Mosquito Control

1.4.1 Larval Control in Pennsylvania

Larvicides, which are chemical or biological agents used to eliminate the larval stage of mosquitoes, are used in standing water [1]. They are used in order to slow the growth of the local mosquito population and are used in response to complaints or disease outbreaks. The main larvicides used in the program are *Bacillus thuringiensis israelensis* (Bti), *Bacillus sphaericus* (Bs), Spinosad, and Methoprene (Table 1.2) [1]. The first two are naturally occurring soil bacteria and have the ability to kill larvae within 24 hours. Ingesting them causes a toxic effect on the mosquito larva alone. Spinosad is also a bacteriological larvicide and can be used on organic farms and gardens. Methoprene is a synthetic growth hormone which interrupts the normal development life cycle of the mosquitoes, keeping them in the larval stage. It is recommended to take a sample to attempt to raise into adults to ensure it is working properly. However, it should be noted that none of these four treatments have an effect on the pupae as they are not actively ingesting anything from their environment. It is recommended to use monomolecular films to prevent pupae from hatching as the films create a barrier on the surface of the water, and the recently hatched mosquitoes drown. Unlike the larvicides, this can impact the species around them.

1.4.2 Adult Control in Pennsylvania

Methods for adult control differ from those for larvae [1]. This involves truck-mounted ultra-low volume (ULV) applications and barrier treatments applied to vegetation. The typical adult control products are composed of pyrethroid insecticides. Barrier treatments are for areas where adult mosquitoes are found in large numbers and will come into contact with the treated vegetation. ULV treatments are sprayed with the intent to kill adult mosquitoes when they are most active, and they are chosen for their minimal risk to humans. People with asthma and others that may be hypersensitive to these chemicals can have some complications. Notifications are made by local vector control specialists to individuals on Pennsylvania's Hypersensitivity Registry when an application is being done within 500 feet of their residence or workplace. Many factors need to be accounted for when deciding to implement adult control, such as species present, environmental controls such as weather, surveillance thresholds, and cases of human acquisition. Thresholds are provided through the DEP. Nuisance control is decided on the number of adults collected in host-seeking traps such as BGs or through complaints. Those mosquitoes that transmit arboviruses such as WNV are considered using a calculation derived from the CDC known as Vector Index or VI. It is the estimated average number of infected *Culex spp.* collected per trap night. Responses recommended vary by county for many reasons ranging from weather to population.

Table 1.2 Comprehensive chart of pesticides to be used in larvae control efforts from the MBDCP guide

Products	Active Ingredient(s)	Habitats	Application Rates	Pretreatment	Residual
Vectobac (G, GS); Aquabac 200G	Bti	Irrigation ditches, roadside ditches, flood water, standing ponds, woodland pools, snow melt pools, pastures, catch basins, storm water retention areas, tidal water, salt marshes, and rice fields	Polluted/3rd and 4th instar areas 10-20 lbs/acre; Unpolluted areas 2.5-10 lbs/acre	No, water must be present	None
Vectobac WDG	Bti	Ditches, catch basins, artificial containers, retention areas	1.75-7 oz/acre (50-200 g/acre)	No, water must be present	None
Vectolex CG; Spheratax	Bs	Wastewater (sewage effluent, sewage lagoons, oxidation ponds, septic ditches, etc.) Stormwater/Drainage Systems (storm sewers, catch basins, drainage ditches, retention, detention and seepage ponds), Mariend and Costal Areas, Water Bodies (natural and man-made), Dormant Rice Fields, Waste Tires	5-20 lbs/acre	No, water must be present	Up to 30 days
Vectolex WSP; Spheratax SPH 50G	Bs	Catch basins, retention ponds, other artificial containers	1 pouch/50 sq. ft.	No, water must be present	Up to 30 days
Vectolex WDG	Bs	STPs, manure lagoons, ditches, catch basins	0.5-1.5 lbs/acre (8-24 oz/acre)	No, water must be present	Up to 30 days
Altosid XRG	Methoprene	Snow pools, salt and tidal marshes, freshwater swamps and marshes, woodlands and meadows, drainage areas, ditches, wastewater treatment plants, retention ponds, storm drains, artificial containers, floodwater areas	*Aedes*, *Ochlerotatus*, *Psorophora*: 5-10 lbs/acre or 1 briquet/200 sq. ft.; *Culex*, *Coquillettidia*, *Anopheles*: 10-20 lbs/acre or 1 briquet/100 sq.ft.	Yes	Up to 30 days
Altosid XR	Methoprene	Storm drains, artificial containers	*Aedes*, *Ochlerotatus*, *Psorophora*: 1 briquet/200 sq. ft.; *Culex*, *Coquillettidia*, *Anopheles*: 1 briquet/100 sq. ft.	Yes	Up to 150 days
Altosid WSP	Methoprene	Storm drains, artificial containers	1 pouch/135 sq. ft.	Yes	Up to 30 days
FourStar Briquets	Bs/Bti	Pre-flooding application, standing water, roadside ditches, irrigation ditches, pastures, salt marshes, ornamental ponds, catch basins and storm drains.	7.5 to 10 lbs/acre up to 20 lbs/acre	Yes	45, 90 and 180 days
FourStar Bti CRG	Bti	Intermittent flooded areas	7.5 to 10 lbs/acre; 10 to 20 lbs/acre where late instar and/or high larval populations are present or if water is heavily polluted	Yes	Up to 40 days
FourStar CRG	Bs	Intermittent flooded areas	7.5 to 10 lbs/acre; 10 to 20 lbs/acre where late instar and/or high larval populations are present or if water is heavily polluted	Yes	Up to 60 days
Natular DT	Spinosad	Garden ponds, bird baths, fish ponds, water gardens, rain barrels, fountains, ornamental pools, roof gutters, standing water	Less than six inches deep: 1 tablet/25 sq. ft. Greater than six inches deep: 1 tablet/50 gallons	Yes	Up to 60 days
Natular G	Spinosad	Certified organic products (OMRI listed), woodland pools, retention ponds, manuare lagoons, catch basins, ditches, artificial containers	5-20 lbs/acre, 1 briquet/100 sq. ft.	Yes	7-10 days
Natular G30	Spinosad	Certified organic products (OMRI listed), pre-flooding application, standing water, roadside ditches, irrigation ditches, pastures, wastewater, manure lagoons, artificial containers	5-20 lbs/acre depending on treatment site	Yes	Up to 30 days
Natular XRT	Spinosad	Certified organic products (OMRI listed), pre-flooding application, standing water, roadside ditches, irrigation ditches, pastures, salt marshes, ornamental ponds, catch basins and storm drains.	1 tablet/100 sq. ft.	Yes	Up to 180 days
CocoBear, BVA 2	Mineral Oil	Marshes, swamps, temporary rain pools, ditches, stagnant pools	3-5 gals/acre, works best for 3rd and 4th instar larvae and pupae	No	None

1.5 The Program Moving Forward

The preceding sections show the standard workflow for Pennsylvania's program. This program uses an integrated approach to ensure that mosquitoes are abated to aid in protecting the residents of the state [11]. Pennsylvania's population has a substantial proportion of individuals over 65 years of age (18.2%) [12]. Those within this age group are at an elevated risk of developing a more severe form of WNV [7]. Therefore, having an initiative like this in place is necessary to help in protecting the health and well-being of the state. Consequently, for this program, as for any program, opportunities for improvement should be considered.

The program guide acts as a standard workflow, but some participating counties add in additional control methods that could prove useful to the rest of the state provided that they are effective. Allegheny County participates in early larval control by treating a portion of City of Pittsburgh catch basins. This type of preventative treatment is believed to aid in reducing the WNV-carrying mosquito populations as they appeal to the most common species habitats. *Culex spp.* mosquitoes prefer standing organic water, and have been observed to use catch basins as one of their breeding sites [8; 9]. Allegheny County uses methoprene in a 150-day briquet form to treat basins during a single round of treatment in early June. The cost is always a concern with these programs due to the reduction in federal funding for state or local programs across the country [13]. Observing changes in the mosquito population before and after treatment will prove difficult as this initiative has been underway in Allegheny County since 2003, and other counties may not participate. In order to find out the effectiveness as well as other factors needed for consideration, a literature review can be done. There is a lack of standardization between programs and states, but there is still an opportunity to learn from other parts of the country [13]. It

is worth examining if this treatment is effective in lowering populations of mosquitoes prone to carrying WNV, and if it is worth rolling out to other Pennsylvania's counties.

2.0 Methods

In order to evaluate the effectiveness of catch basin treatment literature on the subject was examined. The search for relevant material was done using the BIO ONE database due to its extensive collections on a wider variety of topics such as mosquito control. Other databases such as PubMed focus more on clinical symptomology rather than the actual control efforts of the vectors. Multiple variations of search terms were used to narrow down the results to relevant papers such as (Catch Basin) AND (Mosquito) AND (Treatment). These terms and their combinations are shown in Table 2.1. The results obtained from the search term combinations shown in lines 3, 5, and 7 of Table 2.1 were selected for closer inspection as they were combinations of all search terms relevant to the subject.

The inclusion criteria included peer reviewed journals that had papers written in English. The criteria also included that the study had to be conducted in the United States to ensure that there was a no negative impact on generalizing results due to differences in government structures for funding or different species of mosquitoes being controlled that are not found in the United States. The papers were also chosen if they were published within the past ten years in order to ensure up that to date methodology and products were used in the study. The final inclusion criteria were that the study's focus was directly related to the effectiveness of catch basin treatment for mosquito abatement. Once these papers were obtained, their abstracts were reviewed in order to ensure that they met inclusion criteria relevance due to the BIO ONE database's wide variety of subjects causing interference. Those that were considered not to meet the criteria include those unrelated to larval or catch basin mosquito treatment, and those done

abroad. The papers themselves were then read thoroughly to ensure that they met inclusion criteria. Finally, another review of the papers was done to find key points in each of the studies.

Table 2.1 Search terms summary

Search Line number	Total results	Search terms/strategy
#1	1,461	Catch basins
#2	90	Catch basins, Mosquitoes
#3	30	Catch basins, Mosquitoes, treatment
#4	457,593	pesticides
#5	47	#4 and #2
#6	3,004	larvicide
#7	32	#6 and #1

3.0 Results

The total papers yielded from the search was 61. The discrepancy between the total from the combination of the searches 3, 5 and 7 (109) and this total is due to the same papers appearing in more than one of the searches. Those papers published prior to 2009 were eliminated which resulted in 29 not meeting inclusion criteria. Conducting the abstract review resulted in 19 papers not meeting inclusion criteria. This was primarily due to the studies being done abroad and using similar terminology that related to different subjects. There was overlap in the topics from other disciplines that use similar terminology but are not related to the subject being investigated for this paper. For example, "Catch Basin" could return results on catch basin structure or geologic studies on the Ohio River Valley Basin. A further review of the remaining papers resulted in a total of 5 not meeting inclusion criteria, due to being more related to natural species ecology not control efforts or being done abroad. This resulted in a total of 8 papers. These procedures are summarized in Figure 3.1. The papers that met the inclusion criteria were examined again and summarized as described in Table 3.1.

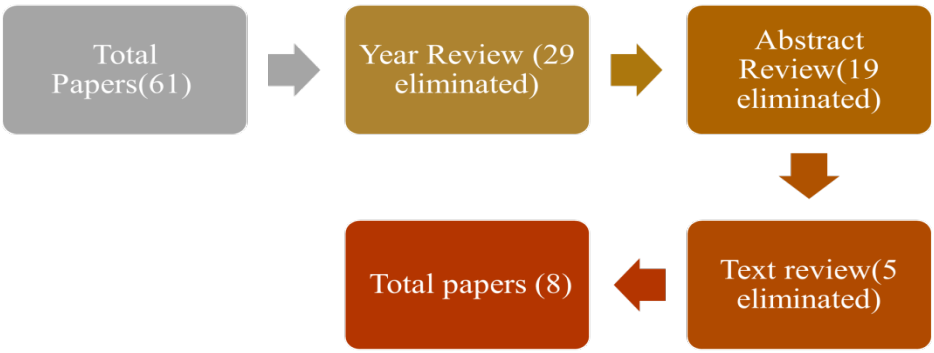


Figure 3.1 Procedure for examining papers

Table 3.1 Summary of Articles Found

Citation	Name, Journal and Study Period	Key Findings
Harbison, Justin E. Nasci, Roger Runde, Amy Et al[14]	Standardized Operational Evaluations of Catch Basin Larvicides from Seven Mosquito Control Programs in the Midwestern United States During 2017 Journal of the American Mosquito Control Association June 2017 to September 2017	•Comparison of Deeper catch basins (those deeper than 5ft) to more shallow ones (under 5ft.) showed a decline in effectiveness of larvicides in the deeper catch basins •Larvicides in pellet or granular form were more effective than briquet forms •Though quality control is recommended, a lack of standardization makes it difficult •Mentioned difficulty with locating instars and pupae in basins
Nasci, Roger S. Runde, Amy B. Henry, Marlon Et al.[15]	Effectiveness of Five Products To Control *Culex pipiens* Larvae In Urban Stormwater Catch Basins Journal of the American Mosquito Control Association April 2016 to August 2016	•Those basins left untreated started producing by June, continuing to do so through October •A significantly lower percentage of late-stage larvae or pupae in treated basins compared to untreated •Post treatment length of effectiveness varied greatly between products •Costs for treatment of 40,000 catch basins varied greatly between products
Harbison, Justin E. Zazra, Dave Henry, Marlon Et al.[16]	Assessment of Reactive Catch Basin Larvicide Treatments Toward Improved Water Quality Using FourStar® Briquets and CocoBear™ Larvicide Oil Journal of the American Mosquito Control Association June 2013 to September 2013	•Exploration of combining methods (FourStar and Cocobear oil) •The combination appeared ineffective •There was no pretreatment done in this area •29 of 30 basins needed treatment over the season (produced more than 12 larvae per dip)
Harbison, Justin E. Henry, Marlon Xamplas, Christopher Et al. [17]	Evaluation of *Culex pipiens* Populations in a Residential Area with a High Density of Catch Basins in a Suburb of Chicago, Illinois	•Attempted to use Gravid traps (not the standard dipping) to measure the effectiveness •Noted due to the design of

Table 3.1 Continued

	Journal of the American Mosquito Control Association June 2013 to September 2013	catch basins for catching runoff, the longevity of treatments could be negatively affected •Notes future studies should test during different years with varying precipitation to gauge population changes
Harbison, Justin E. Henry, Marlon Xamplas, Christopher Et al. [18]	A Comparison of Fourstar™ Briquets and Natular™ XRT Tablets in a North Shore Suburb of Chicago, IL Journal of the American Mosquito Control Association June 2013 to September 2013	•Testing of Natural and Four Star- both showed at least 10 weeks of control (not exceeding 12 per dip) •Controls showed samples of over 50, although both products never reached 20 larvae post treatment over the 15-week period •Nearly all basins showed mosquito growth noting the need for treatment
Harbison, Justin E. Henry, Marlon Xamplas, Christopher Et al.[19]	Experimental Use of Natular™ XRT Tablets in a North Shore Suburb of Chicago, IL Journal of the American Mosquito Control Association June 2011 to September 2011	•20 control and 20 treated within a 0.21 km area •Natular-treated basins contained fewer immature mosquitoes when dipping than the untreated •There was a significant difference in all treated/cleaned basins compared to those untreated •Gravid traps in the area of treated basins also saw a decrease in adults (though they admit this is not the most reliable method) •Mentions present study that cleaning may have a negative effect on larvicides
Sternberg, Morgan Grue, Christian Conquest, Loveday Et al.[20]	Efficacy, Fate, and Potential Effects on Salmonids of Mosquito Larvicides in Catch Basins in Seattle, Washington Journal of the American Mosquito Control Association 2006,2007,2008	• Highlights the importance of treatment •Same strain of bacteriological agent found in multiple products, and active ingredient amount varied •Noted flushing events may reduce efficacy •Found no harm to the local salmonid population
Anderson, John F. Ferrandino, Francis J.	Control of Mosquitoes in Catch Basins in Connecticut With	•Evaluated different products effectiveness in the

Table 3.1 Continued

Dingman, Douglas W. Et al.[21]	*Bacillus thuringiensis israelensis*, *Bacillus sphaericus*, and Spinosad Journal of the American Mosquito Control Association June 2008 to October 2008 June 2009 to October 2009	northeastern USA •VectoBac CG, VectoLex CG and Vectobac 12AS (bacteriological larvicides BS BTI) even at maximum levels did not show a significant drop in population past one week. 3x the dose did, however. •VectoMax WSP is a combination of a BS and BTI and outperformed the others, though is still suggested to have another dose •Rainfall can flush out spores

3.1.1 Key Findings

The findings from this study were ultimately used to answer if catch basin treatment was effective. There was only one paper that showed an increase in mosquito populations in the catch basins, "Assessment of Reactive Catch Basin Larvicide Treatments Toward Improved Water Quality Using FourStar® Briquets and CocoBear™ Larvicide Oil." There are multiple methods for control such as briquet formulation of Methoprene, granular compounds with bacteriological components and even oils to cover the surface of the water so the mosquito larvae cannot access air to breathe. This study looked at the use of the final method, using the oil to create a film on the surface of the water in the catch basin. It was found that the catch basins treated with the combination of briquets and the oil held a larger number of larvae and pupae than the untreated basins. The researchers noted that they neglected to investigate if the active ingredients had antagonistic effects on each other. This paper along with the other papers showed other factors relating to effectiveness.

Another study compared multiple products of varying formulation and active ingredients [15]. Natular XRT (180 day duration), Natular T30 (30 days), Natular G30 (30 days), FourStar Briquet (180 days) and VectoLex FG (30 days) were the ones used for this study. The retreatment intervals were every 16 weeks for the 180 day products and every 28 days for the 30 day products. The first three are spinosad products except Natular G30 is in granular as opposed to tablet form. FourStar Briquet is a combination of *Bacillus sphaericus, B. thuringiensis israelensis* while VectoLex FG is just *B. sphaericus* in a granular form. They found that all of these offer a benefit over the untreated basins, but Natular G30 and VectoLex FG outperformed the others. The authors of this study suggested that the reason for the granular formulations reducing the mosquito larvae and pupae more effectively than the other products was due to the briquets having the issue of being buried in sediment.

This paper along with three others mentioned the concern with the loss of effectiveness with the briquets which accounted for 50% of papers found. The depth of the catch basins and their design allows for the collection of sediment at the bottom. This allows for the creation of the standing organic water that creates an optimal breeding habitat for *Culex* mosquitoes in particular but also poses the issue of the briquet being buried. This can cause the larvicide to become far less effective and was noted to be a concern [14,15,18,19].

Granular formulations appeared to perform well and avoid this issue even in years with heavy rainfall. This phenomenon was observed in, “Efficacy, Fate, and Potential Effects on Salmonids of Mosquito Larvicides in Catch Basins in Seattle, Washington,” as well as three other studies [14,15,21]. Though, “Control of Mosquitoes in Catch Basins in Connecticut With *Bacillus thuringiensis israelensis, Bacillus sphaericus*, and Spinosad,” mentioned multiple rounds of treatment with granular formulation proved to be more effective in this circumstance.

Interestingly, that same study found that in three different products (VectoLex WSP, VectoLex CG and Mosquito Dunks), that the same strain of *B. thuringiensis israelensis* was present when analyzed via Pulsed-field Gel Electrophoresis (PFGE). Also, the concentration of the active ingredient in these products varied from 1% to 46% which those conducting the study hypothesized could directly impact efficacy of these granular formulations.

Another major finding from these studies was the prevalence of *Culex spp.* mosquitoes which are the major vectors for WNV transmission to humans. *Culex pipiens* composed a majority of species found in catch basins, reaching upwards of 94% of the species identified in, "A Comparison of FourStar™ Briquets and Natular™ XRT Tablets in a North Shore Suburb of Chicago, IL". In "Experimental Use of Natular™ XRT Tablets in a North Shore Suburb of Chicago, IL," it was found that the composition of species collected from dipping was 86% were *Culex pipiens* and 14% *Culex restuans*. In that same study the nearby gravid traps that were used to trap adults, all but one of the females captured belonged to the *Culex* genus. The one was identified as *Aedes triseriatus.* These as well as 3 other studies found from the literature search had similar discoveries relating to the species composition [15-19].

Rainfall was noted in two of the studies but was mostly being debated for its effects. It was noted for flushing out the habitat but at the expense of losing the spores from bacteriological treatment in "Control of Mosquitoes in Catch Basins in Connecticut With *Bacillus thuringiensis israelensis, Bacillus sphaericus*, and Spinosad". Alternatively, "Efficacy, Fate, and Potential Effects on Salmonids of Mosquito Larvicides in Catch Basins in Seattle, Washington," noted that VectoLex CG remained efficacious in years with heavier rainfall even though it also has spores as an active ingredient like in the other study.

When the tests were being performed, it was clear that dipping was the most common method as results could be skewed by observing just adult populations. Gravid traps which were used in "Experimental Use of Natular™ XRT Tablets in a North Shore Suburb of Chicago, IL" caused an issue with knowing where the mosquitoes had originated from. Despite the traps being placed close to the catch basins, the origins of the mosquitoes could not be guaranteed.

The cost of treating catch basins was a reoccurring theme being mentioned in four of the studies found through the search. Although, one paper in particular actually calculated out the breakdown of cost between two products which showed the vast range of pricing for these treatments. Roger S. Naci stated in the publication, "Effectiveness of Five Products To Control *Culex pipiens* Larvae In Urban Stormwater Catch Basins," cost was $36,400 for one treatment of VectoLex FG. When using Natular XRT, cost was $192,400 for one round of treatment. These totals were based on 40,000 catch basins along with observations that technicians can treat an average of 200 catch basins per day. These totals included 1,600 person-hours at the cost of $24,000 assuming the average field technician pay level is $15.00 per hour for labor expenses, however, transportation expenses were not included so the totals could be higher [15].

4.0 Discussion

Catch basin treatment is effective and should be considered for adoption statewide in Pennsylvania. However, there are other considerations that need to be taken into account. The MBDC program allows for the tracking, and prediction of disease. It already aids in controlling local mosquito populations in order to avoid human disease outcomes by using control efforts in response to higher rates of disease or reports of mosquito activity [1]. Suggesting that applicators habitually treat catch basins may be able to aid in reducing the overall mosquito population [22]. This will lead to fewer disease outcomes and allow for better protection of the residents of these areas.

The type of treatment used is an important factor, 50% of the articles reviewed indicate that granular formulations are the most effective form. These treatments often last for shorter time intervals, so retreatment will be necessary Future efforts should be made to test current methods used in Allegheny County's catch basin treatment and determining the cost and material breakdown in this region so it can be used elsewhere in the state. There are many initiatives and programs similar to what is found in Pennsylvania all over the United States. However, there is a lack of standardization due to different districts and funding streams. There are mentions of a lack of standardization in these studies [14]. An example from the more mainstream media is an article written for National Geographic about mosquito control Lee County, Florida they have the equipment for aerial spraying whereas other places would never have access to enough funding for communication initiatives let alone aircraft. It's geographic location and heightened perceived need attributes to the larger amounts of funds being allocated [13]. There has been a

disturbing downward trend in funding. From 2004 to 2012 there has been around a 60% drop in federal funding for all mosquito control efforts [8]. The cost can fluctuate greatly depending on products, the number of basins treated and staff time [15]. Cost must be taken into consideration when contemplating how to treat, but the treatment is still necessary. This lack of funding and standardization will leave the country vulnerable in the future to outbreaks of not just WNV, but other mosquito-borne diseases like Zika. This funding deficit can be combated with effective budgeting strategies and even, involving local communities and stakeholders in either treatment with a certified technician or education. This may not just aid in boosting the manpower but can help in terms of educating the public to help with badly needed prevention. All factors have to be taken into account, but the catch basin treatment has been shown to be effective in lowering mosquitoes in the areas in which it is done.

4.1 Mosquito Controls

The MBDC program can add the recommendation to habitually treat catch basins to help in lowering local populations of mosquitoes. Adding any kind of additional intervention to what is present can help protect people from disease and, in some cases, a major nuisance. It is therefore recommended to treat catch basins in these areas habitually if applicable. Making a habit of treating these areas can be one more factor that helps in lowering populations and risk.

These basins can turn into major breeding grounds if they do not drain properly (Figure 1.3). If the county in question has urban and suburban areas that use these as their drainage systems this can lead to proper breeding grounds for the mosquitoes. The neighborhoods in

which these are located can be reviewed via past trapping data, complaints and even attending local meetings to get input. *Culex pipiens* mosquitoes do not typically seek out humans so complaints may not need as much consideration as monitoring vector index, reports of dead birds or information from equine vets. These reports can aid in decisions if the entirety of catch basins cannot be treated, and areas need to be selected.

VectoLex FG can be used for the low impact, and hopefully, it will be easy to apply as it can be dropped through the grates in its water-soluble packets that contain the granular treatment, though in the study they used a measured scoop. This may be cost effective, but more time consuming and prone to error than a water-soluble packet with pre-measured granules [15]. Looking at these studies, briquets have the concern of being buried attached to them so using a granular form Bs treatment like VectoLex FG for treatment might be beneficial. Though treatment efforts with this last only 30 days, so rounds of retreatment would be needed. There are many different treatments available so it may be worth looking at the most cost-effective ones that will be at a lower risk of being buried or washed away in the case of heavy rainfall (Table 1.2). Even when looking at the totals from "Effectiveness of Five Products To Control *Culex pipiens* Larvae In Urban Stormwater Catch Basins," having four rounds of VectoLex FG (June-September) at $36,400 each time is $145,600 which is still more cost effective than Natular XRT at $192,400. Though, this does not consider vehicles or their cost. The availability of vehicles to help transport those doing the treatment and the materials will also need to be considered.

Some counties do participate, but it is good to have this documented in case questions arise. Counties that may already have something like this in place, such as Allegheny County, should be contacted for suggestions on methods, cost and time consumption. This can aid in fine-

tuning the recommendations to Pennsylvania as every state is different, but many have to deal with the WNV-carrying mosquitoes. In 2018, Allegheny County recorded 64,226 *Culex spp.* mosquitoes caught in gravid traps for the season (May-October) [2]. So, it is well worth adding any methods that can help curb mosquitoes, especially those that can carry debilitating disease.

4.2 Limitations

Limitations for this methodology include the lack of review of the unpublished reports or conference abstracts on the subject matter. Another limitation was the use of one database for the literature search. The final limitation was that there was only one researcher available to conduct the literature search and review.

4.3 Future Directions

Many papers suggest that the treatment of catch basins does aid in reducing the mosquito populations in an area [14-21]. That is not to say that future efforts should be made in having larger comparisons over time of treatment benefits. The treatments can be gauged in effectiveness by observing the total number of larvae or pupae found in the treated basins before and after treatments, such as what was done in Justin E. Harbinson's study "Evaluation of *Culex pipiens* Populations in a Residential Area with a High Density of Catch Basins in a Suburb of Chicago, Illinois." This can also be done in a fashion that was seen in another one of his studies in which there were "control" basins that received no treatment at all but were located in an area similar to

those that were [13]. This study, even in one season, could be the basis for a bigger investigation into the effectiveness of methods chosen and then can be adapted to larger scale efforts and different neighborhoods. This acts as an opportunity for students or even local populations to get involved with treatment efforts if they are with a certified technician or simply help with disseminating education materials. This test, in particular, may need more expertise, but the treatment aspect allows for further growth into allowing community involvement. Namely, it works as an education opportunity that plays into the larger picture of a multifaceted approach to mosquito, and additionally, harm reduction.

Education is a powerful tool to be used against contracting WNV. The CDC states that the best protection from WNV is to prevent mosquito bites and offer suggestions on how to communicate this to varying audiences and even encourages community mobilization [23]. When the residents have a say in what research is being done, they are more likely to aid in future efforts. This leads to better research outcomes and long-term contacts for different studies in the future. Having community groups participate in more than presentations can allow for input from new sources and better understanding [24]. Local environmental groups such as bird watchers, hikers, and even local equestrian groups may be good points of contact. They are stakeholders in this due to the effect that WNV has on not just their health, but interests [25]. Equestrian groups are especially important in this regard, due to the mortality rate of WNV being around 35% in horses [26]. Education plays a major role as the residents can then survey their own properties to find potential breeding sites, and know how to apply personal protection effectively [22].

Having residents help with treatment can also be aid in labor deficits, and cost if the county does not have the funding to hire more employees or pay more to existing ones. Having volunteers attend training sessions, and then being available to aid in treatment helps in reducing

the burden of the overall workload. With mosquito populations growing, having these as a recommendation can help neighboring areas, and raise awareness to reduce habitats like artificial containers [27]. Events such as, "The Great Arizona Mosquito Hunt," done in 2015-2017 involved local school groups to train them to do oviposition trapping. Though many did not directly do the trapping, this type of citizen science project can help future endeavors with trapping while providing communities with a say [28]. Other initiatives have been done in the wake of disasters due to a large amount of debris and standing water. These can act as templates or the organizers can even be contacted for information and partnerships [29]. The groups involved in environmental work, schools and even religious organizations can use this opportunity to give back to their communities and make a real impact on protecting the areas in which they live.

4.4 Public Heath Significance

Vector-borne diseases such as West Nile Virus pose a significant public health risk. The virus itself is luckily asymptomatic in most people, but the symptoms that do appear can cause long lasting effects particularly in the immunocompromised and older adults. The neuroinvasive form of the disease in particular poses a very large impact on health and related healthcare costs [6]. There currently is no vaccine commercially available for humans to prevent WNV infection. There are vaccines currently in development including the use of multiple doses of the virus inactivated by formalin that is already approved for use in horses, though they are not yet approved for humans [6]. This only places a larger need on controlling its most common vector the mosquito, especially those of the *Culex* genus. Due to their affinity for catch basins and similar

structures that hold organic standing water, treating these areas to prevent the *Culex spp.* populations from becoming unmanageable is a necessity. Making the practice of treating these catch basins standard can aid in ensuring the safety of the residents of Pennsylvania.

Bibliography

1. Pennsylvania Department of Environmental Protection (2019). *Mosquito-Borne Disease Control Program Manual*.
2. Chancey, C., Grinev, A., Volkova, E., & Rios, M. (2015). The global ecology and epidemiology of West Nile virus. *BioMed research international, 2015*, 376230-376230. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/25866777 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4383390/ https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4383390/pdf/BMRI2015-376230.pdf. doi:10.1155/2015/376230
3. Centers for Disease Control and Prevention, N. C. f. E. a. Z. I. D. N., Division of Vector-Borne Diseases (DVBD). (2019, 6/12/2019). West Nile Virus: Final Cumulative Maps & Data for 1999–2018. Retrieved from https://www.cdc.gov/westnile/statsmaps/cumMapsData.html
4. Organization, W. H. West Nile virus. Retrieved from https://www.who.int/news-room/fact-sheets/detail/west-nile-virus
5. Pennsylvania's West Nile Virus Control Program. http://www.wnvcp.state.pa.us/wnv/FirstFull.aspx
6. Rossi, S. L., Ross, T. M., & Evans, J. D. (2010). West Nile virus. *Clin Lab Med, 30*(1), 47-65. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/20513541. doi:10.1016/j.cll.2009.10.006
7. West Nile virus | West Nile Virus | CDC. (2018, 2018/12/10). Retrieved from https://www.cdc.gov/westnile/index.html
8. And, S. H. (1995). House Mosquitoes of the U.S.A., Cules pipiens complex. *Wing Beats, 6*(2), 8-9. Retrieved from http://vectorbio.rutgers.edu/outreach/species/sp1.htm.
9. Crans, W. J. (2014). Mosquito Biology: Rutgers Center for Vector Biology. Retrieved from http://vectorbio.rutgers.edu/outreach/species/rest.htm
10. Novak, R. (1992). The asian tiger mosquito, Aedes albopictus. *Wing Beats, 3*(3), 5. Retrieved from http://vectorbio.rutgers.edu/outreach/species/sp8.htm.
11. West Nile Virus in the United States: Guidelines for Surveillance, Prevention, and Control. (2013, 2013). Retrieved from https://www.cdc.gov/westnile/resources/pdfs/wnvguidelines.pdf
12. Bureau, U. S. C. (2019). U.S. Census Bureau QuickFacts: Pennsylvania. Retrieved from https://www.census.gov/quickfacts/fact/dashboard/PA/AGE775218
13. McKenna, M. (2016). Disorganized Mosquito Control Will Make US Vulnerable to Zika. Retrieved from https://www.nationalgeographic.com/science/phenomena/2016/02/29/zika-mosquito-control/.
14. Harbison, J. E., Nasci, R., Runde, A., Henry, M., Binnall, J., Hulsebosch, B., . . . Ruiz, M. O. H. (2018). Standardized Operational Evaluations Of Catch Basin Larvicides From Seven Mosquito Control Programs In The Midwestern United States During 2017. *Journal of*

the American Mosquito Control Association, 34(2), 107-116. Retrieved from <Go to ISI>://BIOSIS:PREV201800730398. doi:10.2987/18-6732.1

15. Nasci, R. S., Runde, A. B., Henry, M., & Harbison, J. E. (2017). Effectiveness Of Five Products To Control Culex Pipiens Larvae In Urban Stormwater Catch Basins. *Journal of the American Mosquito Control Association, 33*(4), 309-317. Retrieved from <Go to ISI>://BIOSIS:PREV201800249328
https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-33/issue-4/17-6686.1/Effectiveness-of-Five-Products-To-Control-iCulex-pipiens-i-Larvae/10.2987/17-6686.1.short
https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-33/issue-4/17-6686.1/Effectiveness-of-Five-Products-To-Control-Culex-pipiens-Larvae-In/10.2987/17-6686.1.short.
16. Harbison, J. E., Zazra, D., Henry, M., Xamplas, C., & Kafensztok, R. (2015). Assessment Of Reactive Catch Basin Larvicide Treatments Toward Improved Water Quality Using Fourstar (R) Briquets And Cocobear (Tm) Larvicide Oil. *Journal of the American Mosquito Control Association, 31*(3), 283-285. Retrieved from <Go to ISI>://BIOSIS:PREV201500754689
https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-31/issue-3/moco-31-03-283-285.1/Assessment-of-Reactive-Catch-Basin-Larvicide-Treatments-Toward-Improved-Water/10.2987/moco-31-03-283-285.1.short.
17. Harbison, J. E., Henry, M., Xamplas, C., & Dugas, L. R. (2014). Evaluation Of Culex Pipiens Populations In A Residential Area With A High Density Of Catch Basins In A Suburb Of Chicago, Illinois. *Journal of the American Mosquito Control Association, 30*(3), 228-230. Retrieved from <Go to ISI>://BIOSIS:PREV201400759680
https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-30/issue-3/14-6414R.1/Evaluation-of-iCulex-pipiens-i-Populations-in-a-Residential-Area/10.2987/14-6414R.1.short
https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-30/issue-3/14-6414R.1/Evaluation-of-Culex-pipiens-Populations-in-a-Residential-Area-with/10.2987/14-6414R.1.short. doi:10.2987/14-6414r.1
18. Harbison, J. E., Henry, M., Xamplas, C., Berry, R., Bhattacharya, D., & Dugas, L. R. (2014). A Comparison Of Fourstar (Tm) Briquets And Natular (Tm) Xrt Tablets In A North Shore Suburb Of Chicago, Il. *Journal of the American Mosquito Control Association, 30*(1), 68-70. Retrieved from <Go to ISI>://BIOSIS:PREV201400334658
https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-30/issue-1/13-6355.1/A-Comparison-of-Fourstar-Briquets-and-Natular-Xrt-Tablets-in/10.2987/13-6355.1.short. doi:10.2987/13-6355.1
19. Harbison, J. E., Henry, M., Xamplas, C., & Berry, R. (2013). Experimental Use Of Natular (Tm) Xrt Tablets In A North Shore Suburb Of Chicago, Il. *Journal of the American Mosquito Control Association, 29*(3), 237-242. Retrieved from <Go to ISI>://BIOSIS:PREV201300700339
https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-29/issue-3/12-6303.1/Experimental-Use-of-Natular-XRT-Tablets-in-a-North-Shore/10.2987/12-6303.1.short. doi:10.2987/12-6303.1

20. Sternberg, M., Grue, C., Conquest, L., Grassley, J., & King, K. (2012). Efficacy, Fate, And Potential Effects On Salmonids Of Mosquito Larvicides In Catch Basins In Seattle, Washington. *Journal of the American Mosquito Control Association, 28*(3), 206-218. Retrieved from <Go to ISI>://BIOSIS:PREV201200699735 https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-28/issue-3/11-6173.1/Efficacy-Fate-and-Potential-Effects-on-Salmonids-of-Mosquito-Larvicides/10.2987/11-6173.1.short. doi:10.2987/11-6173.1
21. Anderson, J. F., Ferrandino, F. J., Dingman, D. W., Main, A. J., Andreadis, T. G., & Becnel, J. J. (2011). Control Of Mosquitoes In Catch Basins In Connecticut With Bacillus Thuringiensis Israelensis, Bacillus Sphaericus, And Spinosad. *Journal of the American Mosquito Control Association, 27*(1), 45-55. Retrieved from <Go to ISI>://BIOSIS:PREV201200560948 https://bioone.org/journals/Journal-of-the-American-Mosquito-Control-Association/volume-27/issue-1/10-6079.1/Control-of-Mosquitoes-in-Catch-Basins-in-Connecticut-With-span/10.2987/10-6079.1.short https://bioone.org/journals/journal-of-the-american-mosquito-control-association/volume-27/issue-1/10-6079.1/Control-of-Mosquitoes-in-Catch-Basins-in-Connecticut-With-Bacillus/10.2987/10-6079.1.short. doi:10.2987/10-6079.1
22. Epa, U. S., Ocspp, Opp, & Fead. (2016). Success in Mosquito Control: An Integrated Approach. Retrieved from https://www.epa.gov/mosquitocontrol/success-mosquito-control-integrated-approach.
23. Wallerstein, N., & Duran, B. (2010). Community-based participatory research contributions to intervention research: the intersection of science and practice to improve health equity. *Am J Public Health, 100 Suppl 1*(Suppl 1), S40-46. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/20147663 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2837458/pdf/S40.pdf. doi:10.2105/AJPH.2009.184036
24. Hacker, K. (2013). Community-Based Participatory Research. Retrieved from http://dx.doi.org/10.4135/9781452244181. doi:10.4135/9781452244181
25. Newman, E. West Nile Virus Still Impacts Birds | Wildlife Medical Clinic at Illinois. Retrieved from https://vetmed.illinois.edu/wildlife/2017/08/01/west-nile-virus-still-impacts-birds/
26. West Nile Virus. (2009, 2009). Retrieved from https://www.vet.k-state.edu/vhc/services/equine/timely-topics/wnv-fact-sheet.pdf
27. Rey, J. R., Walton, W. E., Wolfe, R. J., Connelly, C. R., O'Connell, S. M., Berg, J., . . . Laderman, A. D. (2012). North American wetlands and mosquito control. *Int J Environ Res Public Health, 9*(12), 4537-4605. Retrieved from https://www.ncbi.nlm.nih.gov/pubmed/23222252. doi:10.3390/ijerph9124537
28. Tarter, K. D., Levy, C. E., Yaglom, H. D., Adams, L. E., Plante, L., Casal, M. G., . . . Walker, K. R. (2019). Using Citizen Science to Enhance Surveillance of Aedes aegypti in Arizona, 2015–17. *Journal of the American Mosquito Control Association, 35*(1), 11-18. Retrieved from http://dx.doi.org/10.2987/18-6789.1. doi:10.2987/18-6789.1
29. Law, E. How to do a Community Clean-up Lowering Aedes mosquito populations. In I. F. o. R. C. a. R. C. Societies (Ed.).