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Effectiveness of a Buffalo Turbine and A1 Mist Sprayer for the Areawide Deployment of Larvicide for Mosquito Control in an Urban Residential Setting

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Abstract

The control of medically important container-inhabiting mosquitoes is an ongoing challenge for mosquito control operations. Truck-mounted application equipment is a common option for rapid areawide larvicide deployment utilized by mosquito control operations. We tested the effectiveness of two truck-mounted sprayers (A1 Super Duty + Buffalo Turbine CSM3), for the deployment of water-dispersible biopesticides (VectoBac WDG:VectoLex WDG 50:50). Sixty residences within four residential neighborhoods in New Jersey were treated in 2019 and 2020. Three empty bioassay cups were placed in specific locations on each property (front yard/ back yard/ side of house), with an additional cup placed in an adjacent catch basin. This approach was replicated in two untreated control neighborhoods. Following larvicide application, cups were subjected to bioassays wherein larval mortality was tracked through adult eclosion. Overall, average larval mortality rates were 56% higher in treated cups compared against untreated controls. Mortality rates were affected by cup location, with 39% mortality in bioassay cups from back yards, 54% in those from the sides of houses, 73% in front yards, and 76% from cups in catch basins. Mortality did not differ significantly between the four treated neighborhoods, nor by the type of sprayer used. Our research shows that truck-mounted sprayers can be an effective method for larvicide deployment in residential neighborhoods, but effectiveness may depend upon the location of the target treatment area in relation to residences and other geographic obstacles.

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Keywords

larvicide; areawide; mosquito control

Larvicides are important tools for mosquito control operations. In the United States (U.S.) they are often used for preventative or nonemergency vector control, or in combination with adulticides during emergency operations (Likos et al. 2016). In the northeastern U.S., biological larvicides are deployed more commonly than adulticides (Burtis et al. 2020). Among these larvicides, biopesticides, including *Bacillus thuringiensis israelensis* (*Bti*) and *Lysinibacillus sphaericus* (previously *Bacillus sphaericus*), are favored by mosquito control operations due to their limited environmental persistence and reduced impact on nontarget species, relative to many synthetic options (Lacey 2007, Arthurs and Dara 2019). Resistance to *Bti* is uncommon, making it a good rotation option when resistance emerges to other larvicides (Bruehl et al. 2020). Unfortunately, use of these biopesticide formulations can be challenging in heavily urbanized regions like the coastal northeastern U.S. In these areas, the most commonly treated larval habitats are catch basins and open containers, both of which are often treated by hand using back-pack sprayers. Additionally, water-holding containers may be located on private property that mosquito control staff cannot access (Irwin et al. 2008, Bartlett-Healy et al. 2012). Little is known regarding the effectiveness of areawide larvicide deployment methods when used to target these important mosquito larval habitats.

Treating catch basins can be time-consuming and has shown mixed results in effectiveness and efficacy trials. An initial study in the Chicago metropolitan area showed that a single application of Natular XRT (spinosad) or FourStar Briquets (*Bti* + *L. sphaericus*) could provide larval control for up to eight weeks (Harbison et al. 2014). Further investigation in the Chicago area showed that efficacy varied depending upon the timing of application and the pesticide formulation deployed. Hydrology, depth, and sediment content of targeted catch basins could also impact control efficacy (Harbison et al. 2016, Nasci et al. 2017, Harbison et al. 2018). Treatment of catch basins with biopesticides (*Bti* + *L. sphaericus*) in urban Atlanta reduced the number of *Culex* spp. larvae within the catch basins but the adult trap collection counts nearby were unaffected (McMillan et al. 2019). This indicates that catch basins can be effectively treated for localized reduction of mosquito immature stages, but the impact on adult populations may not be strong enough to reduce mosquito-borne disease risk. This is likely due to the presence of abundant alternate larval habitats, including water sources such as sewage treatment ponds and drainage ditches, or containers on private and abandoned lots, that are difficult to find and treat. Source reduction and educational campaigns can reduce entomological risk for some container inhabiting species (Healy et al. 2014), but efficacy of these campaigns may depend upon their proximity to natural aquatic sites (Majambere et al. 2010) and how long they are maintained. Larvicides can be deployed aerially, but this may be difficult for local mosquito control operations to provide as an on-demand service.

The use of truck-mounted sprayers may be an effective method for the areawide deployment of larvicides in urban areas (Tidwell et al. 1994, Faulde et al. 2008, Wilke et al. 2021). In northern Florida (FL), an application on a military base caused 50% mortality of the target species (*Aedes albopictus* (Skuse) (Diptera: Culicidae)/ *Aedes aegypti* (L.) (Diptera: Culicidae)) in bioassays (Aldridge 2018). In New Jersey (NJ) the spatial penetration of a larvicide from a truck-mounted Buffalo Turbine air blast system was determined in an open field setting. This application caused 98% mortality of *Ae. albopictus* larvae up to 100 m from the truck location, although this varied by application rate (Williams et al. 2014). In another study from Trenton, NJ, combinations of larvicide and adulticide applications using a truck-mounted sprayer were evaluated. This approach effectively suppressed *Ae. albopictus* adults (Unlu et al. 2019). Few studies have evaluated the effectiveness of reaching infested containers located in different places around residences (Williams et al. 2014) and none have included catch basins. Additionally, while Buffalo Turbine air blast systems are commonly deployed as low-volume sprayers, there are many alternative sprayer models available for use by vector control applicators (Hoffmann et al. 2007).

To address these gaps in our understanding regarding the effectiveness of truck-mounted sprayers for the control of container-inhabiting mosquitoes, we evaluated the impact of larvicide applications using two types of truck-mounted sprayers: an A1 Super Duty Mist Sprayer (ADAPCO, Sanford, FL) or a Buffalo Turbine air blast system (Model: CSM3) (Buffalo Turbine, Springville, NY). The application areas were in two urban NJ counties (Bergen/ Mercer). We replicated the experiment over two years (2019 and 2020). Two biopesticides, *Bti* and *L. sphaericus* were deployed. Empty containers were placed around residential plots to catch larvicides, as described in Unlu et al. (2019). We also placed containers within adjacent catch basins to determine whether they were effectively treated by our larvicide application. We aimed to test whether truck-mounted sprayers are a viable option for the areawide deployment of larvicides to treat containers and catch basins in urban residential areas and whether effectiveness varied with different sprayer equipment.

Methods

Application Site

This research was conducted in urban residential neighborhoods in Bergen and Mercer Counties in NJ. Three neighborhoods were selected in each county. Two were used to test the deployment of larvicide with either an A1 Super Duty Mist Sprayer or a Buffalo Turbine air blast system (Model: CSM3). The third neighborhood served as an untreated control wherein no spray event occurred. In Mercer County, the treatment sites (N 40°14’12.20“, W 74°45’6.34” and N 40°13’27.49”, W 74°44’15.81”) were located in Trenton NJ, while the untreated control site was located in nearby Hamilton Township NJ (N 40°12’7.82”, W 74°43’33.12”). In Bergen County, the treatment sites were in Little Ferry NJ (N 40°50’32.39”, W 74° 2’18.89”) and Paramus NJ (N 40°57’6.80”, W 74° 3’15.58”). The untreated control location was also in Paramus NJ (N 40°58’15.88”, W 74° 4’24.43”). Each neighborhood covered an area of approximately 40 ha (~100 ac) (Fig. 1). Four plastic bioassay cups (473 ml volume, Uline, Pleasant Prairie, WI) were placed on 15 properties within each neighborhood. Cups were set within three areas on each property (front/ side/ back of house), with a fourth cup placed in an adjacent catch basin. Catch basins were located near targeted properties. They were covered with metal grates and were approximately one meter deep. The cups in catch basins were suspended five to ten cm below the grates with wires. All basins were located on the same road as the spray route and clear of vegetation, leaf litter, and other debris. The average distance between the collection cups and the spray truck was 10.4 m (± 0.8) for those in front yards, 20.2 m (± 1.0) in side yards, 30.0 m (± 1.3) for back yards, and 4.6 m (± 0.5) for catch basins. Each of the six neighborhoods contained a total of 60 cups, with 360 cups deployed per treatment year. Applications were conducted once in 2019 and again in 2020. The type of sprayer that was used to treat each neighborhood was switched between years to control for any neighborhood characteristics that might affect larvicide deployment (e.g.: topography, road density, or average lot size).

Description of Spray Activities

In 2019 and 2020, the A1 Super Duty and Buffalo Turbine were both calibrated prior to deployment. A different set of sprayers was used in each year to account for any variation in machine quality. Both systems have 378.5 L tanks, with vertical mist throws of up to 30 m. The primary difference between systems is that the A1 Super Duty is smaller and lighter than the Buffalo Turbine. Both systems were equipped with a Micronair AU 5000 rotary atomizer (Micron Group, Sandown, Isle of Wight, UK) with 70 mm fan blades set at 35 degrees. Calibration of the spray equipment was conducted using a timed bucket collection method wherein the volume of larvicide solution dispensed over one minute is measured, with a target of 11.36 L of spray per minute (Murray et al. 2021). Red dye (Food Drug and Cosmetic Red 40, Spectrum Chemical Corp, New Brunswick, NJ) was added to the product at a rate of 1.37 kg to 190 L to increase the visibility of droplets for spray characterization work to assist with droplet size and density calculations. Both machines were characterized to dispense droplets of a similar size. A line of twelve stations were established perpendicular to the spray path, with one station every 9.1 m for 100.5 m. Two replicate runs were conducted for each sprayer. A compact disk jewel case with a Kromekote card (CTI Paper, Sun Parie, WI) attached with a box clip was placed at each station. The glossy surfaces of the cards were placed face up, with the jewel case underneath serving as a weight to hold the card in position and preventing ground moisture from soaking into the Kromekote cards. Droplet size and density were measured using two sets of 12 stations. ImageJ was used to determine droplet size and density at each of the 12 stations.

The spray events occurred on 11–12 October 2019 and 17–18 June 2020. All applications were conducted in the early morning between 1:00 hrs and 7:00 hrs. A 50:50 (VectoBac WDG:VectoLex WDG) suspension (0.12 kg/ L) was prepared according to label instructions, no more than 12 h prior to the application. Product was mixed and loaded using a 150 gallon gasoline-powered mixing station (Mid-Atlantic Services, Elkton, MD). The Buffalo Turbine and A1 mist sprayers were loaded in the beds of standard ¾ ton pick-up trucks and driven at a speed of 16 km/h, with a starting point that was chosen based upon wind direction. The nozzle height for the A1 mist sprayer was 179 cm and it was placed on a truck bed at 91 cm (total height: 270 cm), while the Buffalo turbine had a nozzle height of 114 cm on top of the same 91 cm truck bed (total height: 205 cm) The pressure of both machines was set to deliver a flow rate of 11.36 L of spray per minute. The airflow of the A1 mist sprayer was 2.87 cubic meters per second, while the airflow of the Buffalo turbine was 3.89 cubic meters per second. The average airflow was measured using a handheld kestrel anemometer at three positions directly above the spray head. The final application rate of each product was 285 g/ha, for a total of 570 g/ha combined. Start and stop times along with the truck route were recorded. Wind speed, direction, ambient temperature, and relative humidity were also recorded using a portable weather station, Davis Instruments, VantagePro2™ (Hayward,CA). Applications in both counties were performed no more than 2 d apart.

Ae. aegypti Rearing

The strain of *Ae. aegypti* used for this study was Rockefeller (ROCK), a well-established strain that is susceptible to a range of insecticides (Pal 1967). Though *Ae. aegypti* is not endemic in NJ, we selected this strain because it is commonly used in susceptibility studies and this ensured that the larvae used were fully susceptible to the biopesticide residue in the bioassay cups. This colony is also highly productive, so can produce large numbers of eggs on short notice. This allowed for us to produce the 7,200 larvae needed for each year of the study in coordination with the field application. Mosquitoes were maintained at 28 (±1)°C and 70% (±10%) RH with a 12:12 h (L:D) cycle. Adults were supplied with a 10% sugar solution and fed cattle blood through an artificial feeder. Females deposited eggs onto germination papers, which were dried for long term storage. To hatch eggs, the papers were submerged in DI water and held under a vacuum for 30 min. They were then allowed to sit in the water for 24 h, after which larvae were transferred into trays containing DI water and Hikari Cichlid Gold large Fish pellets (Kyorin Food Industries, Japan) at a density of 200 larvae per L.Third instar larvae were used in bioassays.

Bioassay Description

Bioassay cups were retrieved from the field one hour following each application and stored in a freezer at −20°C for no more than two weeks before use in bioassays. When bioassays were run on different days, they were evenly split between treatment groups so that we could determine whether time in storage affected effectiveness. Prior to initiating the bioassays, cups were sorted, and damaged or wet cups were discarded. In 2019, 19 cups were discarded, while in 2020 a total of 78 were discarded. More cups were discarded in 2020 than 2019 as more moisture was found in the cups. Cups were then filled with 250 ml of DI water, sealed with a lid, and swirled by hand for approximately 20 sec. This ensured that any pesticide that landed inside the cups was washed into solution. Eight small holes were then added to the lid of each cup to allow for air circulation. Twenty third-instar *Ae. aegypti* larvae were added to each cup, along with 65 mg of crushed fish pellets. Bioassay containers were closed and placed inside an incubator at 28 (± 1)°C and 70% (±10%) RH with a 12:12 h (L:D) cycle. The containers were checked every 24 h for the next 7 d and daily larval mortality was recorded, through adult eclosion.

Statistical Analyses

Larval mortality was recorded for 7 d, or until all adults eclosed in bioassay cups. This was the final measure of mortality used for analysis of the bioassay data. A binomial model was constructed in R version 4.0.3 using the glm command in the MASS package (R Core Team 2014). Parameters were selected according to their AIC values. Those which decreased the AIC score by > 2 against the null model were included, along with interactions, as fixed effects. The final model parameters were application year (2019/ 2020), bioassay cup location (catch basin/ front/ side/ back of house), and the interaction between the two. Direct comparisons between groups were determined using a *posthoc* Tukey's test (Yandell 2017). Calibration data for the sprayers were also compared between sprayer type and application year. The droplet density and size were compared in two separate ANOVAs, both of which included distance, sprayer type, and year as factors. Interactions between distance and the other two factors were also included to determine whether effects varied with distance. A square-root transformation was applied to the droplet density data to conform with the assumption of normality.

Results

In 2019, wind speeds were between 0–6.4 km/h, the average temperature was 14.8°C, and average RH was 41.5%. During the 2020 application wind speeds were between 0–1.6 km/h, the average temperature was 16.4°C, and average RH was 79.2%. There was no precipitation during either application period. During calibration, the droplet sizes did not differ significantly between sprayer types (df = 1,82, F-value = 0.232, $P = 0.631$), but did between years (df = 1,82, F-value = 4.839, $P = 0.031$). In 2019 the droplet size for the Buffalo Turbine was 88.5 μm (± 10.4), and 103.7 μm (± 7.4) for the A1 Super Duty. Average droplet size for the 2020 application was 117.2 μm (± 10.8) for the Buffalo Turbine and 109.5 μm (± 9.6) for the A1 Super Duty. Droplet size decreased significantly with distance from the sprayer (df = 1,82, F-value = 38.155, $P < 0.001$), and there was a significant interaction between distance and sprayer type (df = 1,82, F-value = 5.463, $P = 0.022$), but not year (df = 1,82, F-value = 1.882, $P = 0.174$). During calibration, the droplet densities differed significantly between years (df = 1,82, F-value = 13.118, $P < 0.001$), but not sprayer type (df = 1,82, F-value = 2.938, $P = 0.091$). Droplet densities were overall lower in 2020 than in 2019 for both sprayers; the A1 Super Duty density was higher than for the Buffalo Turbine. Average droplet density for the Buffalo Turbine in 2019 was 13.5 (± 6.8) per cm^2 and 23.5 (± 8) per cm^2 for the A1 Super Duty. In 2020 droplet density was 1.93 (± 0.62) per cm^2 for the Buffalo Turbine and 2.45 (± 1.3) per cm^2 for the A1 Super Duty. Droplet density decreased significantly with distance (df = 1,82, F-value = 22.397, $P < 0.001$) and there was a significant interaction between distance and year (df = 1,82, F-value = 5.868, $P = 0.018$), but not sprayer type (df = 1,82, F-value = 0.001, $P = 0.973$) (Fig. 2).

In the laboratory bioassays, three parameters improved the model according to AIC values and had significant effects on the mortality of *Ae. aegypti* larvae after 7 d; cup location (catch basin/ front/ side/ back of house) (df = 3,397, F-value = 24.2, $P < 0.001$), year (2020/2019) (df = 1,397, F-value = 8.1, $P = 0.005$), and their interaction (df = 3,397, F-value = 3.2, $P < 0.025$). Sprayer type (Buffalo Turbine/A1 Super Duty) was not included in the final model as it did not improve the AIC score, nor did duration of storage of treated cups at −20°C prior to use in bioassays. Mortality rates of larvae were 53.9% (± 4.0) in bioassay cups placed on the sides of houses, and 38.9% (± 4.0) in cups placed in back yards. Overall, mortality rates were higher in bioassay cups that had been placed in catch basins and the fronts of houses, rates of 76.4% (±3.3) and 73.4% (± 3.2), respectively. Mortality rates were higher in 2019 at 65.4% (± 2.8) than in 2020 at 54.6% (± 2.7). The results of the posthoc

Tukey test comparing these groupings are presented in Fig. 3. Larval mortality rates in the control bioassay cups were 7% in 2019 and 2% in 2020.

Discussion

Comparing the effectiveness of the two truck-mounted applicator models, both the Buffalo Turbine and A1 Super Duty were similarly effective and sprayer model was dropped from the final model as it was not an important factor indicated by the AIC score. Buffalo Turbines are commonly deployed for areawide larvicide application for mosquito control in the U.S. (Williams et al. 2014, Garcia-Luna et al. 2019, McAllister et al. 2020, Wilke et al. 2021). Our results suggest that if the equipment is calibrated with similar airflow characteristics as well as fan and nozzle outlet orientation; both sprayers should provide similar spray deposits. There is a wide variety of low volume and ultra-low volume sprayers used by vector control operators (Hoffmann et al. 2007). The A1 Super Duty model used in this study was only capable of liquid applications, whereas the Buffalo Turbine was capable of both granular and liquid applications but was 31% more expensive. The increased cost of the Buffalo Turbine is attributed to this additional versatility which may not be a priority for certain mosquito control programs. Ultimately, the suitability of equipment may depend more on the versatility of the machine needed to specifically target application areas and operational budget resources. Here we provide a direct comparison between truck-mounted sprayer models, along with an experimental design that can be used to evaluate new or existing models to be used for the areawide deployment of larvicides in urban environments. Although both machines are comparable in terms of performance and ease of use, the A1 Super Duty has a considerably smaller footprint (1.8 m × 1.07 m) than the Buffalo Turbine (2.74 m × 1.09 m) and weighs 41% less than the Buffalo Turbine model with the hopper attachment. As a result, the A1 Super Duty may be somewhat easier to install, store, and maintain. The A1 Super Duty also uses a wireless remote controller, which provides additional convenience over the Buffalo Turbine.

The overall effectiveness of the applications was approximately 11% higher in 2019 than 2020. This may have been due to differences between the specific units deployed. We observed differences in the droplet density and size between years. Specifically, the droplet density was higher and droplet sizes were smaller in 2019 than 2020. Weather conditions during each application may have also affected effectiveness between years as the treatments occurred at different times of year. Temperatures varied by < 2°C between years, but wind speeds and relative humidity (RH) did differ. Overall wind speeds were low, but the maximum in 2019 was 4.8 km/h higher than that in 2020. Higher wind speed combined with smaller droplet sizes may have allowed the spray to travel further in 2019 than 2020. The RH was also 37% higher during the 2020 application. High RH can increase droplet size (Yu et al. 2008, Maciel et al. 2018) and may further reduce the distance droplets travel (Zhu et al. 1994). The most significant differences in effectiveness between years were observed in cups placed in residential back yards, which was reduced by 24% in 2020 relative to 2019 (Fig. 3). The combination of high humidity, slightly lower wind speeds, and larger droplets may have limited drift and therefore the treatment of back yards, which were furthest from the road. Additional research is needed to determine the ideal conditions for the deployment of larvicides in urban areas using truck-mounted sprayers. Specific guidance must also be developed regarding the seasonal timing of deployment to maximize control effectiveness during the summer when humidity is high.

A previous trial by Unlu et al. (2019) in NJ tested combined applications of larvicides and adulticides using a truck-mounted Ag-Mister LV-8 low-volume sprayer in residential neighborhoods. They observed 81% mortality in bioassays similar to those used in our field trials. Deploying larvicides alone, we observed 58% mortality compared against untreated controls in 2019 and 43% in 2020. Furthermore, the Unlu et al. (2019) study applied larvicides and adulticides in combination. Pyriproxyfen was the larvicide utilized in this study, to which *Ae. albopictus* is highly susceptible (Gómez et al. 2011). This may have increased overall larval mortality in their study. They also treated the alleys behind houses, potentially making their application more even, further increasing effectiveness. During the Zika outbreak in Florida truck-mounted sprayers were also used to deploy larvicides in tandem with other methods (McAllister et al. 2020). This was not a formal trial, but rather an outbreak response, making effectiveness difficult to compare against other studies. We used a combination of *Bti* and *L. sphaericus*. The ROCK colony used in our study has been found to be susceptible to L. sphaericus in the past (Rojas-Pinzón et al. 2018), but the susceptibility of *Ae. aegypti* field populations to *L. sphaericus* can vary (Monnerat et al. 2004, Santana-Martinez et al. 2019, Su et al. 2019). There is evidence that *Bti* may synergize the larvicidal activity of *L. sphaericus* (Wirth et al. 2000) and even in field populations with low susceptibility to *L. sphaericus* it has been found to be effective when used in combination with *Bti* (Su et al. 2019). Different larvicide active ingredients and their formulations should be compared directly to determine best practices for the areawide deployment of larvicides using truck-mounted sprayers.

The location of bioassay cups within the residential properties had the strongest effect on effectiveness in our trials. The front yards of targeted properties were treated more effectively than the sides or back yards of houses. There is evidence that treatment can be effective out to 100 m in open fields lacking obstructions (Williams et al. 2014), but vegetation and other obstructions can prevent effective penetration of insecticide droplets into a target area (Barber et al. 2008). A study of pyriproxyfen application using a ULV sprayer resulted in no significant difference in effectiveness out to 23 m in a residential neighborhood (Doud et al. 2014). However, other evaluations using methoprene have demonstrated reduced effectiveness as distance from the spray route increases (Bibbs et al. 2018). This may depend upon the equipment used and obstructions present within a given neighborhood. Surprisingly, our study showed that the treatment of catch basins was highly effective when using both sprayer types, showing 73% higher mortality rates compared against untreated control catch basins. This suggests that truck-mounted sprayers can simultaneously treat residential containers and catch basins, increasing treatment efficiency and saving mosquito control operations time and resources.

The primary alternative method to truck-mounted sprayers for the areawide deployment of larvicides is aerial application. However, aerial deployments are generally more suitable for open wetland habitat, rather than residential neighborhoods where targeted approaches may be more practical. Our results suggest that truck-mounted sprayers can effectively treat larval habitats in urban environments, but habitat location relative to the truck path must be considered. Catch basins and unobstructed areas can be treated from the road but larval habitat behind buildings may remain difficult to effectively treat using this deployment method. We have also shown that alternative types of spray equipment can be deployed if Buffalo Turbines are not available or are too expensive. Additional research is needed to determine the effectiveness of truck-mounted sprayers to control different mosquito species as well as the effect of deploying other larvicide-active ingredients or formulations. Our application rate was 570 g/ha, but Williams et al. (2014) observed significantly higher efficacy at 800 g/ha than 400 g/ha, indicating the need to determine optimal application rates. Furthermore, the evaluation of effectiveness against field populations of mosquitoes would help determine whether the control pressure exerted using truck-mounted sprayers is strong enough to impact entomological risk for humans. Ultimately, larvicide application using truck-mounted sprayers presents a relatively cost-effective method for timely areawide application of larvicides in urban residential settings that are otherwise difficult to access.

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Fig. 1.

Map showing the larvicide application areas in Bergen and Mercer Counties along with the truck routes that were followed during the spray operations. Orthoimages are from 2015 and were downloaded from the USGS Earth Explorer database. The control plots for Bergen and Mercer Counties do not show truck application spray routes because they were not treated.

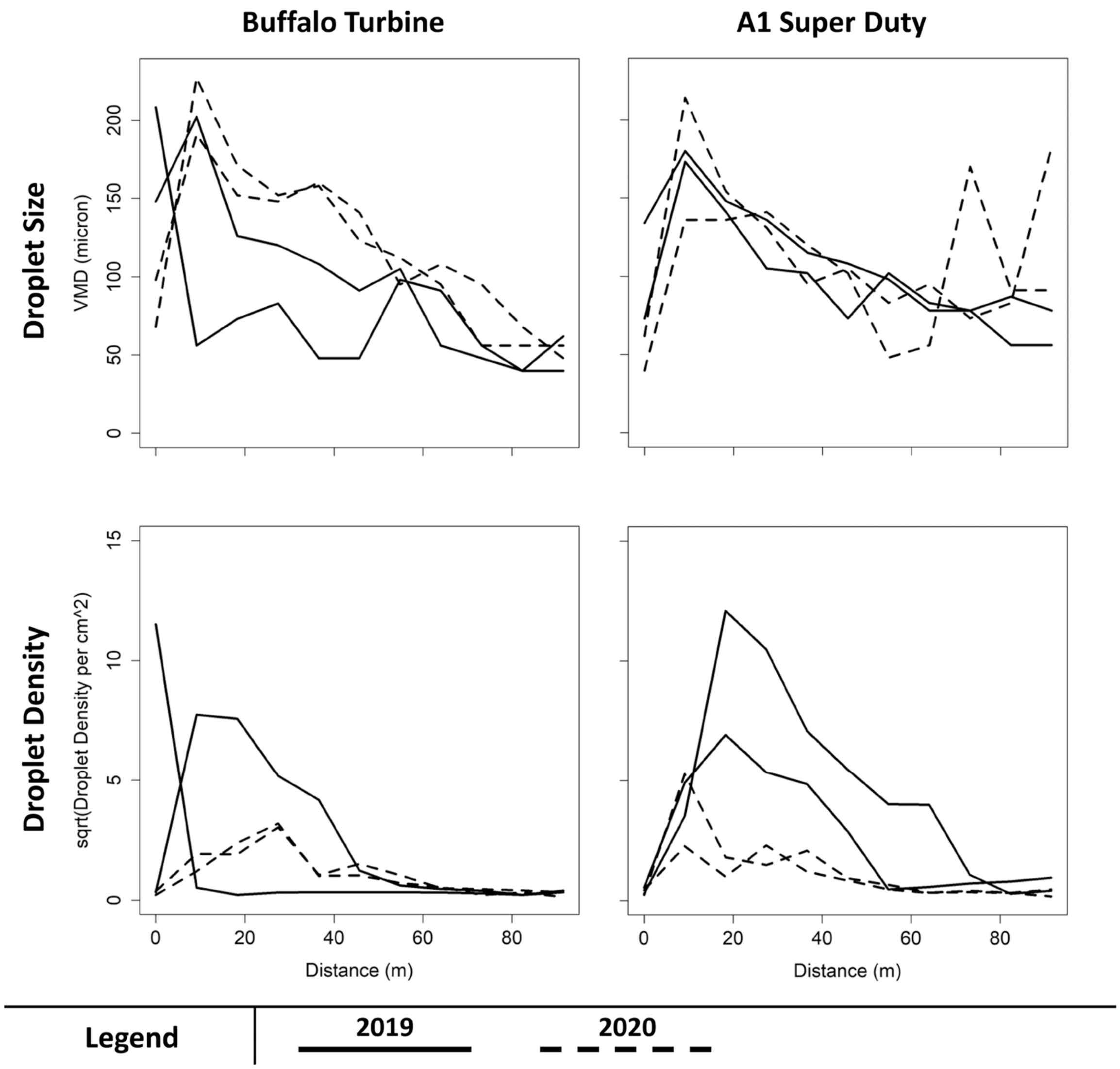

Fig. 2.

Plots showing the relationship between distance and droplet size/ droplet density during the calibration testing. Two runs were conducted for each year. The data are split by sprayer type (A1/ Buffalo) and year, with 2019 as solid lines and 2020 as dashed lines. Droplet density data are square-root transformed to match the ANOVA.

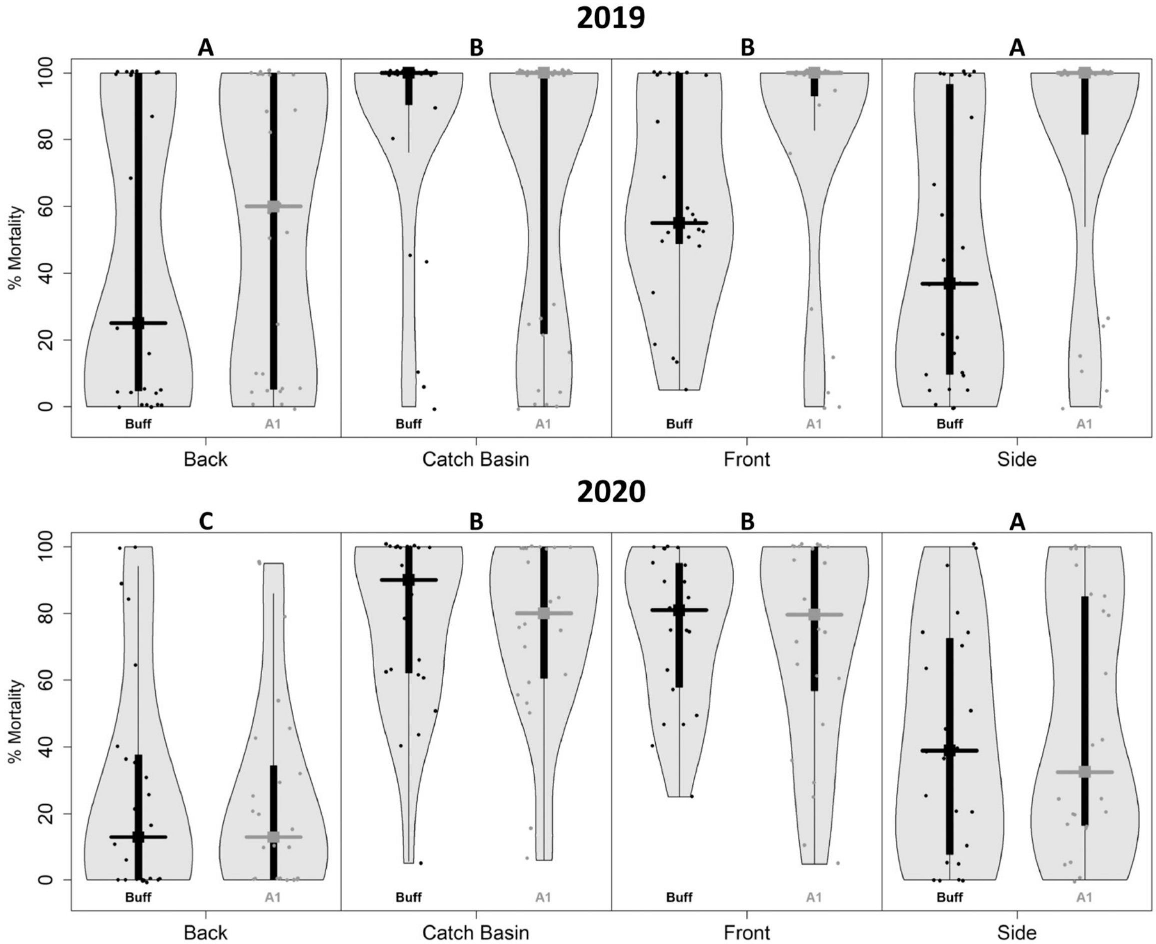

Fig. 3.

Violin plots showing larval mortality rates after 7 d in treated cups (untreated controls not shown). Since treatment site was not significant, each violin shows all the data across sites in Bergen and Mercer Counties. The grey 'violins' are a visualization of the data density, so that more data are clustered where the violin wider. The large points and horizontal bars represent the median values, and the vertical bars are the interquartile range. Letters above the plots signify differences between cup locations and years according to a posthoc Tukey's test. Groups with different letters differ significantly ($P < 0.05$). Buff = Buffalo Turbine CSM3.