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EFFECTIVENESS OF FIVE PRODUCTS TO CONTROL *CULEX PIPIENS* LARVAE IN URBAN STORMWATER CATCH BASINS

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ABSTRACT. Effectiveness in controlling mosquito larvae in stormwater catch basins in the North Shore Mosquito Abatement District (northeastern Cook County, IL) was determined for 2 extended-duration larvicides indicating up to 180 days of control on their labels (Natular™ XRT, FourStar® Briquet) and 3 larvicides indicating up to 30 days of control (Natular™ T30, Natular™ G30, and VectoLex® FG). Over the course of the 26-wk study, catch basins receiving the extended-release products were treated twice (an initial treatment in early April followed by a re-treatment after 16 wk), and catch basins receiving the shorter-duration products were treated every 28 days, with the 1st treatment occurring during the 1st week in April. Control in an individual catch basin was considered to have failed if late-stage larvae or pupae were found in 2-dip samples taken from the catch basin. Control for a treatment was considered to have failed if >25% of catch basins treated with the product failed at a given time period posttreatment. All of the products evaluated in the study demonstrated some degree of control; however, the Natular XRT–, FourStar Briquet–, and Natular T30–treated basins rarely achieved the effectiveness threshold of ≤25% of catch basins failing. By comparison, basins treated with Natular G30 were below that threshold for 3 of 4 wk every treatment round and VectoLex® FG was consistently below that threshold for all 4 wk posttreatment for every treatment round. Compared with untreated catch basins, the total season pupal production was reduced by approximately 48% in the Natular XRT–, FourStar Briquet–, and Natular T30–treated basins, and by 87% and 99% in the Natular G30– and VectoLex FG–treated basins, respectively. Operational quality control observations indicated that effective control (i.e., ≤25% of catch basins failing) ranged from 3 to 12 wk posttreatment for catch basins treated with Natular XRT and from 5 to 9 wk with VectoLex FG, and that there was considerable geographic variation in the duration of effectiveness. The results indicate that 30-day re-treatments with granular formulations in difficult-to-control areas may provide a more cost-effective outcome than using 1 or 2 applications of extended-duration larvicides.

KEY WORDS Catch basin, *Culex pipiens*, effectiveness, larvicide, mosquito

INTRODUCTION

Catch basins are essential components of stormwater management systems, serving as inlet devices to intercept water from roads and other drainage courses. They are ubiquitous in urban areas and often incorporate sumps to prevent debris and sediments in the runoff from entering the system (Debo and Reese 2003). Due to the tendency for these sumps to hold water and organic material for long periods, catch basins have been targets of mosquito control efforts in urban settings for >100 years (Chase and Nyhen 1903, Bunker 1917) and have been identified as important sources of *Culex pipiens* L. (Munstermann and Craig 1977, Harbison et al. 2014b). Since the 1999 introduction and subsequent spread of West Nile virus (WNV) across the continental USA, and the association of WNV with catch basin–produced *Cx. pipiens* (Anderson et al. 2006), controlling mosquitoes in catch basins has become a priority in many mosquito abatement districts, the focus of considerable research, and the motivation for development of new mosquito control products.

The North Shore Mosquito Abatement District (NSMAD), located in northeastern Cook County, IL, encompasses approximately 70 mi^2 of primarily urban/suburban residential habitat. Communities served by NSMAD were identified as high-risk areas for WNV human cases during the 2002 WNV outbreak in the region (Ruiz et al. 2007). A total of 158 WNV cases were reported from NSMAD communities in 2002, and confirmed cases have been reported from the district almost every year since that time (NSMAD 2016). In response, NSMAD shifted much of its surveillance and control effort from nuisance/floodwater species to *Cx. pipiens*, WNV, and the approximately 40,000 catch basins located in the district.

Like many abatement districts dealing with this increased need to manage mosquitoes in catch basins, NSMAD looked to extended-release briquettes or tablets as a solution. Available with a variety of active ingredients (AI; e.g., methoprene, spinosad, *Bacillus thuringiensis israelensis* de Barjac, *Lysinibacillus sphaericus* (Meyer and Neide)) allowing rotation to avoid resistance development and with labels indicating up to 150–180 days of control, these products offer the prospect of season-long control with a single application. However, performance of extended-release products in NSMAD catch basins has proven quite variable. While all products/AI evaluated evidently reduce the number of immature

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mosquitoes, evaluations conducted in NSMAD catch basins found that they did not eliminate larvae from the catch basins and effectiveness waned long before the maximum control duration stated on the product labels, often as soon as 5 wk after application (Harbison et al. 2013, 2014a, 2014b, 2015). The variation in effectiveness has been attributed to the briquette or tablet being flushed out or degraded by the high water flow some of these structures experience or buried too deeply in the sediments to provide sufficient AI (Knepper et al. 1992, Li et al. 2012, Harbison et al. 2015), with the net result being that a single treatment frequently is not sufficient and re-treatment is needed. This is consistent with observations of extended-duration product effectiveness in catch basins in other areas (Stockwell et al. 2006, Anderson et al. 2011).

In 2016, NSMAD conducted an intensive, experimental study to evaluate 2 extended-duration (up to 180 day) and 3 short-duration (up to 30 day) larvicide products in catch basins to determine how control effectiveness compared with the maximum control duration stated on the product label, and if re-treatment at label-specified intervals provided effective control. We also implemented an extensive quality control program to monitor effectiveness of our routine operational catch basin control practices, which employed 1 extended-release product and 1 short-duration product during 2016. The overall objective was to identify products and re-treatment schedules that would provide effective and economical control options, so the 3rd component of the project was an analysis of overall application costs for extended-release and short-duration products.

MATERIALS AND METHODS

Study Sites

The NSMAD is divided into 3 zones (A, B, C), each of which is subdivided into approximately 1-mi^2 (1.6-km^2) operational areas to facilitate larvicide and adulticide operations. Curbside catch basins in 5 neighborhoods were selected for inclusion in the evaluation of the 2 extended-release formulations and 3 short-duration formulations (Fig. 1). Within each of these 5 neighborhoods, 60 catch basins were identified and labeled with unique numbers for a total of 300 catch basins in the study. Within each of the 5 neighborhoods, 10 catch basins were treated with each of the 5 formulations and 10 basins served as untreated controls for a total of 50 catch basins in each treatment group and 50 untreated controls in the study.

Larvicide Formulations, Application Rate, and Re-treatment Schedules

The larvicide products selected for evaluation were Natular™ XRT, FourStar® Briquet, Natular™ T30, Natular™ G30, and VectoLex® FG. Details for each product are shown in Table 1. A single briquette or tablet was applied to each catch basin as instructed on the product labels. For the 2 granular formulations, 20 g of the product was applied to each catch basin using a 2-tablespoon scoop for the VectoLex FG and a 1-tablespoon scoop for the Natular G30. The 1st application occurred the week of April 4, 2016, and repeated every 28 days for the Natular T30, Natular G30, and VectoLex FG products. The extended-release formulations (Natular XRT, Four-Star Briquet) were first applied the week of April 4, 2016. By 16 wk postapplication (112 days), it became apparent that the single application would not provide season-long control so the products were reapplied during the last week in July 2016.

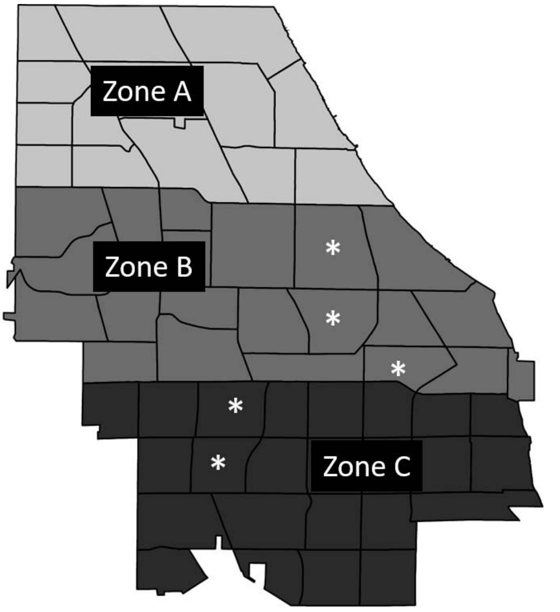

Fig. 1. North Shore Mosquito Abatement District showing operational areas (black outlines) divided into 3 zones (A, B, and C shown in different shades of gray), and location of the 5 catch basin treatment neighborhoods in zones B and C (shown by *).

Sampling and Determination of Control Effectiveness

Each catch basin was sampled weekly from the 1st week in April through the 2nd week in October 2016, which encompasses the primary *Cx. pipiens* season in the Chicago area. Sampling was accomplished by removing the lid grate and taking 2 dips with a standard 350-ml dipper. The sample was observed to determine if mosquito larvae and pupae were present. If so, we recorded whether early-stage larvae (1st or 2nd instar) or late-stage larvae (3rd or 4th instar) were present. Presence of pupae and the number of pupae in the 2-dip sample were also recorded. If no larvae or only early-stage larvae were present, we considered this evidence of effective control and

Table 1. Larvicide products evaluated in catch basins, showing application rates and re-treatment intervals.

Product	Manufacturer	Active ingredient	Maximum control duration[1]	Application rate per catch basin	Re-treatment interval
Natular™ XRT	Clarke Mosquito Control Products, Roselle, IL	Spinosad	180 days	1 tablet	16 wk
FourStar® Briquet	Central Life Sciences, Schaumburg, IL	*Bacillus sphaericus*, *B. thuringiensis israelensis*	180 days	1 briquette	16 wk
Natular™ T30	Clarke Mosquito Control Products, Roselle, IL	Spinosad	30 days	1 tablet	28 days
Natular™ G30	Clarke Mosquito Control Products, Roselle, IL	Spinosad	30 days	20 g of granules	28 days
VectoLex® FG	Valent BioSciences Corporation, Libertyville, IL	*B. sphaericus*	4 wk	20 g of granules	28 days

[1]The maximum control duration is excerpted from the product label and is usually expressed as effective up to the duration shown.

scored the basin as "pass." If late-stage larvae or pupae were present, we considered this evidence of a control failure and scored the basin as "fail," indicating that re-treatment would be necessary. A similar pass/fail criterion for evaluating control effectiveness was used previously to characterize larvicide performance in catch basins (Siegel and Novak 1997). This is consistent with guidance from the World Health Organization that states, "The frequency of larvicidal treatment is determined based on the reappearance of fourth instar larvae or pupae, in the case of common larvicides and bacterial larvicide products" (WHO 2005), and the fact that late-stage larvae and pupae would have been exposed to any AI in the catch basin for several days and should not have survived. However, based on previously published results using extended- or short-duration products in catch basins (e.g., Siegel and Novak 1997; Harbison et al. 2015, 2016), we recognize that 100% control effectiveness is an unrealistic expectation so we set our acceptable level at 75% of the catch basins scoring "pass" at a given duration posttreatment. When the "fail" rate exceeded 25% of the basins at a given time postapplication, we considered that a control failure for the treatment. Percent fail was compared between untreated and treated catch basins each week using a chi square test for comparison of proportions (MEDCALC 2017).

Quality Control Evaluations

In addition to the experimental study described above, a quality control program was implemented to monitor effectiveness of NSMAD catch basin operations. During 2016, routine NSMAD control procedures consisted of treating all catch basins within an operational area (Fig. 1) with either Natular XRT tablets or with 20 g VectoLex FG. All catch basins within an operational area can be treated by NSMAD field staff within a 3- to 4-day period. The quality control evaluation consisted of sampling 20–30 catch basins within a given operational area at a specified duration postapplication using the same procedure as described above to determine pass or fail (i.e., presence of late-stage larvae or pupae in 2 standard 350-ml dips constitutes control failure). Quality control inspections of operationally treated catch basins began during the 4th week in June when 78% of untreated catch basins evaluated in the experimental study contained late-stage larvae and pupae (Table 2). The percentage of catch basins failing was calculated for each operational area and duration posttreatment. The number of pupae was not recorded for the quality control evaluations.

Cost of Treating Catch Basins

The cost of conducting a single round of treatment to 40,000 catch basins in NSMAD was calculated using the current cost of 2 larvicide products (VectoLex FG and Natular XRT), the hourly wage of seasonal field technicians, and the average number of catch basins a field technician can treat in 1 day (derived from NSMAD operational data).

Rainfall Data

Regional rainfall trends were inferred by obtaining weekly rainfall totals from National Oceanic and Atmospheric Administration weather station GHCND:USC00111497, which is located within the NSMAD (NOAA 2017).

RESULTS

None of the catch basins in the study contained late-stage larvae or pupae during the 1st week in April when the 1st larvicide applications were made. Late-stage larvae and pupae were observed in untreated catch basins only intermittently from the

Table 2. Percent fail in catch basins treated with extended-release products and untreated basins during 2 rounds of treatment. Observations were made for 16 wk following treatment in the 1st treatment round and for 10 wk in the 2nd treatment round.

				% fail[2]		
Month	Treatment round	Week posttreatment	Weekly rainfall total (mm)[1]	Untreated	FourStar® Briquet[3]	Natular™ XRT[3]
Apr	1	1	16.5	0	0	0
	1	2	2.0	0	0	0
	1	3	11.7	4	0	0
	1	4	24.4	0	0	0
May	1	5	39.6	2	0	0
	1	6	68.6	0	0	0
	1	7	4.1	4	2	0
	1	8	33.8	22	24	6*
June	1	9	31.2	46	40	8*
	1	10	28.7	57	54	35*
	1	11	9.9	69	70	49*
	1	12	23.1	78	81	67
July	1	13	18.8	91	75*	65*
	1	14	0.8	85	83	72
	1	15	24.1	86	73	73
	1	16	102.6	49	52	36
Aug	2	1	0.8	91	68*	33*
	2	2	5.1	93	67*	38*
	2	3	31.8	69	41*	21*
	2	4	42.4	50	42	28*
Sept	2	5	29.5	57	24*	17*
	2	6	25.1	77	54*	44*
	2	7	5.8	83	79	60*
	2	8	13.7	82	86	71
Oct	2	9	18.3	75	70	69
	2	10	24.6	38	42	31

[1]Total weekly rainfall data obtained from National Oceanic and Atmospheric Administration National Centers for Environmental Information (https://www.ncdc.noaa.gov/cdo-web/) for weather station GHCND:USC00111497, which is located within the North Shore Mosquito Abatement District.
[2]Percentage of catch basins with late-stage larvae or pupae (= fail). Weeks with a percent fail >25% are italicized.
[3]Percent fail significantly lower in treated than in untreated catch basins during the sample week noted by an asterisk (*). $P \leq 0.05$ chi square test for comparison of proportions.

1st week in April through the last week in May (Table 2). The percentage of untreated catch basins with late-stage larvae and pupae did not exceed 25% until the 1st week in June, exceeded 25% thereafter through the end of the study, reached peaks of 91–93% during the 1st week in July and the 1st 2 weeks in August, and exceeded 50% each week through early October.

During the 1st treatment round with the extended-release formulations, the percentage of FourStar Briquet–treated basins failing (i.e., containing late-stage larvae and pupae) was significantly lower than that found in the untreated basins only during the 13th week posttreatment. The percentage of Natular XRT–treated basins failing was significantly lower than in the untreated basins through 11 wk posttreatment and again during 13 wk posttreatment (Table 2).

During the 2nd round of treatment with extended-release formulations (starting the 1st week in August), the percentage of FourStar Briquet–treated basins that failed was significantly lower than the untreated basins for 5 of the 1st 6 wk posttreatment but did not differ from the untreated basins for weeks 7 through 10. The percentage of Natular XRT–treated basins that failed was significantly lower than the untreated basins through 7 wk posttreatment and did not differ from the untreated basins for weeks 7 through 10. Though there was evidence of control from the extended-release formulations, i.e., fewer basins containing late-stage larvae and pupae than in untreated basins particularly in the 2nd treatment round, the percentage of basins failing exceeded 25% during most weeks of the study (Table 2).

For the short-duration products, the 1st 2 treatment rounds are excluded from analysis since the percentage of untreated basins with late-stage larvae and pupae did not exceed 25% until the 1st week of June, which marked the 1st week posttreatment of the 3rd treatment round (Table 3). The 7th treatment round was monitored only for 2 wk posttreatment due to declining mosquito populations. During the 3rd through 7th rounds of treatment with Natular T30, the percentage of treated basins failing was significantly lower than the untreated basins for 3 of the 4 wk posttreatment in rounds 3 and 5, 1 wk in rounds 4

Table 3. Percent fail in catch basins treated with short-duration products and untreated basins during 7 rounds of treatment. Observations were made for 4 wk following the 1st 6 treatment rounds and for 2 wk during the 7th treatment round.

Month	Treatment round	Week posttreatment	% fail[1]			
			Untreated	Natular™ T30[2]	Natular™ G30[2]	VectoLex® FG[2]
Apr	1	1	0	0	0	0
	1	2	0	0	0	0
	1	3	4	0	0	0
	1	4	0	0	0	0
May	2	1	2	0	0	0
	2	2	0	0	0	2
	2	3	4	2	0	0
	2	4	22	8	4*	6*
June	3	1	_46_	10*	0*	0
	3	2	_56_	_30*_	8*	8*
	3	3	_69_	_41*_	_46*_	21*
	3	4	_78_	_73_	_60_	_28*_
July	4	1	_91_	_56*_	8*	2*
	4	2	_85_	_77_	18*	8*
	4	3	_86_	_71_	_53*_	19*
	4	4	_49_	_38_	_52_	16*
Aug	5	1	_91_	_67*_	6*	0*
	5	2	_93_	_69*_	25*	0*
	5	3	_69_	_36*_	_39*_	9*
	5	4	_50_	_35_	_39_	17*
Sept	6	1	_57_	_38_	8*	2*
	6	2	_77_	_55*_	24*	6*
	6	3	_83_	_68_	_54*_	11*
	6	4	_82_	_80_	_73_	17*
Oct	7	1	_75_	_56*_	8*	2*
	7	2	_38_	16*	4*	0*

[1]Percentage of catch basins with late-stage larvae or pupae (= fail). Weeks with a percent fail >25% are italicized.
[2]Percent fail significantly lower in treated than in untreated catch basins during the sample week noted by an asterisk (*). $P \leq 0.05$ chi square test for comparison of proportions.

and 6, and both weeks in round 7 (Table 3). In the Natular G30–treated basins, the percentage of treated basins failing was significantly lower than the untreated basins for 3 wk posttreatment in all 4 of the 4-wk rounds, and both weeks of the 7th treatment round. In the VectoLex FG–treated basins, the percentage of treated basins failing was significantly lower than the untreated basins during every week of the 4-wk rounds, and both weeks of the 7th treatment round.

Despite evidence of reduced production of late-stage larvae and pupae in the basins treated with Natular T30, the percentage of basins failing exceeded 25% throughout all but 2 wk of the 18-wk study. The Natular G30–treated basins provided passing levels of control (≤25% with late-stage larvae and pupae) for the 1st 2 wk of each of the treatment rounds. In the VectoLex FG–treated basins, the percent fail exceeded 25% only during 1 wk of the entire study, the 4th week of the 3rd treatment round, and was below 25% for the remaining 17 wk of the study.

The total number of pupae collected throughout the entire season in each of the treatment groups provides an additional index of control effectiveness and shows that the 2 rounds of Natular XRT and FourStar Briquet treatments and the 7 rounds of Natular T30 treatments reduced pupal production by 46–47% over the course of the season compared with the number of pupae collected in the untreated catch basins (Table 4). The percent reduction in pupae was 87% and 99% in the Natular G30– and VectoLex FG–treated basins, respectively. The number of weeks the control failure rate was ≤25%, out of the 18 wk of the study after the 1st week in June, is significantly correlated with the percent reduction in pupal production (Pearson $r = 0.97$, $r^2 = 0.95$, $P < 0.001$). The number of weeks that the percent treated catch basins containing late-stage larvae or pupae was significantly less than the percent untreated basins containing late-stage larvae or pupae was also correlated with the percent reduction in pupae (Pearson $r = 0.89$, $r^2 = 0.79$, $P = 0.04$), though not as strongly as the percent control failure (Table 4).

Quality Control Evaluations

Over the course of the 2016 season, 63 operational areas treated with Natular XRT were inspected up to 12 wk posttreatment and 61 operational areas treated with VectoLex FG were inspected up to 8 wk posttreatment (Table 5). In the Natular XRT–treated areas, failures (>25% of catch basins failing within

Table 4. Total number of pupae collected and the percent reduction in pupal production throughout the entire season in untreated and treated catch basins and the number of weeks each treatment had a fail rate ≤25% or in which the percent fail in the treated catch basins was significantly less than in the untreated catch basins.

Treatment	Total no. pupae	% reduction in pupae from untreated	No. weeks with % fail ≤25% (n = 18)[1]	No. weeks with % fail significantly less than in untreated (n = 18)[2]
Untreated	1,321	—	—	—
Natular™ T30	715	46	2	10
FourStar® Briquet	699	47	1	6
Natular™ XRT	699	47	3	11
Natular™ G30	176	87	10	14
VectoLex® FG	13	99	17	18

[1]Number of weeks the treatment failed (i.e., catch basin contained late-stage larvae or pupae) out of the 18 total weeks of the study from the 1st week of June through the 2nd week of October is significantly correlated with percent reduction in pupae (Pearson $r = 0.97$, $r^2 = 0.95$, $P < 0.001$).

[2]Number of weeks with the percent fail significantly less than in untreated basins. Out of the 18 total weeks of the study from the 1st week of June through the 2nd week of October is significantly correlated with percent reduction in pupae (Pearson $r = 0.89$, $r^2 = 0.79$, $P = 0.04$).

the operational area) were observed at approximately 3 wk posttreatment and the frequency of failures increased as time posttreatment increased (Fig. 2A), though some operational areas maintained passing levels until 11 wk posttreatment. In the VectoLex FG–treated operational areas, failures were first observed at approximately 5 wk posttreatment, the frequency of failures increased following that time, and some areas maintained passing levels of control until almost 10 wk postapplication (Fig. 2B). This is similar to the duration of control Siegel and Novak (1997, 1999) obtained using VectoLex® CG in catch basins.

Consistent with previously published observations, we found that performance of the products varied considerably, and also observed a pattern of variation in effectiveness among the different zones across the district. Overall, 40% of the Natular XRT–treated operational areas failed by 12 wk posttreatment. However, in the areas located in zone A at the north end of the district, only 17% failed by 12 wk posttreatment while 73% failed by 12 wk posttreatment in the zone C areas at the south end of the district (Table 5). In the VectoLex FG–treated operational areas, the failure rate by 8 wk posttreatment was 26% over the entire district but ranged from 9% in the zone A areas to 38% in the zone C areas.

Cost of Catch Basin Treatments

We estimated the labor and material costs associated with a single round of treatment of the 40,000 catch basins in NSMAD. Based on observations that our field technicians can treat an average of at least 200 catch basins per day, it will take a minimum of 200 person-days (1,600 person-hours) and cost $24,000 (at NSMAD's average summer field technician pay level of $15.00/h) in labor expenses, regardless of which product is used. At 200 catch basins/person/day, it would require 10 field technicians to complete 1 round of treatment for all 40,000 catch basins in the district in 4 wk.

For material costs, we used the lowest and highest cost products in our analysis to determine the range of expenses for pesticides. The cost of VectoLex FG is based on our current cost of $283.00 for a 40-lb (18,143-g) bag, which will treat 907 catch basins at an application rate of 20 g/basin for a cost of $0.31/catch basin. The cost of Natular XRT is estimated at our current cost of $928.00/case of 220 tablets, or $4.21/basin. The results indicate that the estimated cost of 1 treatment round with VectoLex FG is

Table 5. Results of quality control inspections showing the number and percentage of operational areas with >25% of catch basins failing by 12 wk after treatment with Natular™ XRT or by 8 wk after treatment with VectoLex® FG.

	Natular XRT			VectoLex FG		
Zone	No. operational areas inspected	No. operational areas failing[1] by 12 wk	% operational areas failing by 12 wk	No. operational areas inspected	No. operational areas failing[1] by 8 wk	% operational areas failing by wk
A	30	5	17	11	1	9
B	11	4	36	21	4	19
C	22	16	73	29	11	38
Total	63	25	40	61	16	26

[1]Control in an operational area is considered to have failed if >25% of catch basins sampled in the area contain late-stage larvae or pupae.

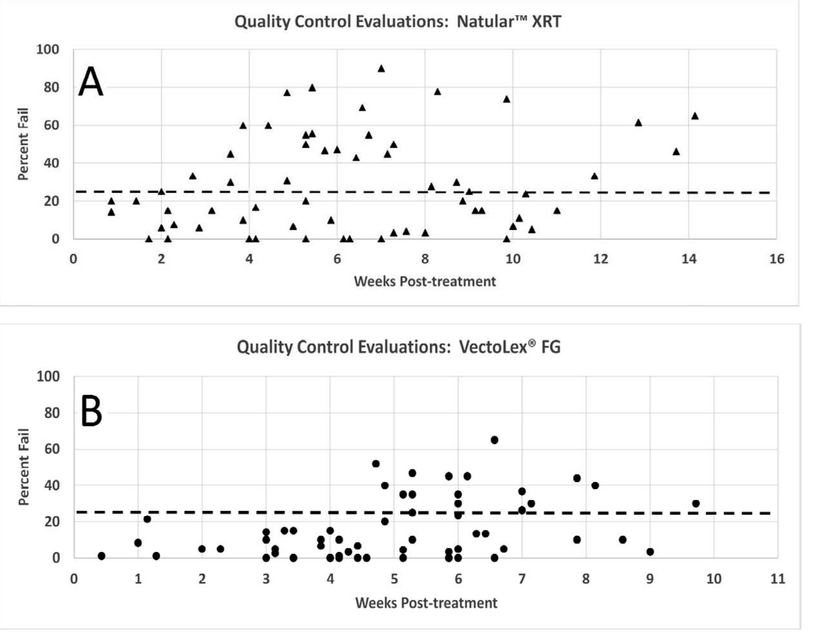

Fig. 2. Percent fail for (A) Natular™ XRT– and (B) VectoLex® FG–treated catch basins during weekly quality control inspections. Dashed line shows the 25% fail level. Each point represents the percentage of catch basins containing late-stage larvae or pupae in an operational area at the duration posttreatment shown on the *x*-axis.

$36,400 and the cost of 1 treatment round with Natular XRT is $192,400. This estimate does not include vehicle cost (gasoline, maintenance, insurance, etc.).

DISCUSSION

Left untreated, approximately half of the catch basins in the study area were producing mosquitoes by early June. By early July, essentially all untreated catch basins contained late-stage larvae and pupae, and continued producing mosquitoes at high levels through early October. Week-to-week variation in the percentage of untreated catch basins containing late-stage larvae or pupae was likely due to natural fluctuations in mosquito abundance as well as heavy rainfall events that may have produced sufficient flow to flush egg rafts, larvae, and pupae from the catch basins. For example, 102.6 mm of rain fell during the last week of July, which was associated with a decrease to 49% of untreated catch basins containing late-stage larvae and pupae from 86% the previous week.

The results demonstrated that all products evaluated provided a measurable level of control; however, the implied degree of effectiveness was variable depending on which measure of control effectiveness was being used. Using a significant difference in percentage of catch basins containing late-stage larvae or pupae between treated and untreated basins as a basis for effectiveness evaluation, the FourStar Briquet showed effective control consistently up to 42 days posttreatment. The Natular XRT appeared to provide effective control for 49 days posttreatment, and the Natular T30 effectively reduced the percentage of catch basins containing late-stage larvae and pupae for up to 21 days posttreatment. However, using the pass/fail criteria in which presence of late-stage larvae or pupae in >25% of catch basins indicates a control failure, the FourStar Briquet–, Natular XRT–, and Natular T30–treated catch basins rarely achieved this level of control effectiveness. The levels of control noted above were achieved using 2 treatments with the extended-release products and 7 treatments with Natular T30, and were associated with a 46–47% reduction in pupal production compared with untreated basins.

The percentage of catch basins containing late-stage larvae and pupae was consistently lower than in untreated basins for 21 days posttreatment in the Natular G30 treatments and for 28 days posttreatment in the VectoLex FG–treated catch basins. Unlike the extended-release and Natular T30 products, the Natular G30 and VectoLex FG granular formulation products were below the 25% failure rate for most intervals posttreatment (i.e., 2 of 4 wk posttreatment with Natular G30 and 4 of 4 wk during most rounds for VectoLex FG). Reductions in pupal production compared with untreated basins were considerably higher with these products and ranged from 87–99%. These results indicate that the 25% failure threshold is a better criterion for inferring control effectiveness than comparing the presence of late-stage larvae in untreated and treated basins and validates the WHO (2005) recommendation regarding reappearance of 4th-stage larvae or pupae as an indicator that retreatment is needed. Using these criteria, it appears that even though all products evaluated provided some level of control, the most effective control was provided by Natular G30 and VectoLex FG, retreated every 28 days.

The potential reasons for these differences in control effectiveness were not investigated as part of this study, but we speculate that the briquette and tablet formulations, as a point source of AI, are more prone to being buried in sediment or flushed out, and the granular formulations provide a dispersed source of AI in the catch basin that may be less prone to being completely flushed out or buried. This contradicts suggestions from laboratory simulations that pellets are more likely to be flushed from catch basins than ingots (briquettes) (Li et al. 2012), but is consistent with field observations indicating tablets are frequently lost from catch basins, presumably from flushing or degradation (Harbison et al. 2015).

Results of the quality control evaluations reinforce observations from the experimental study. Within operational areas treated with Natular XRT, control failures (i.e., >25% of treated basins containing late-stage larvae and pupae) started as early as 3 wk posttreatment, but control was still at passing levels up to 11 wk posttreatment in some operational areas. In operational areas treated with VectoLex FG, control was at passing levels up to 5 wk posttreatment and some areas displayed effective control (not exceeding 25% failure) up to 9 wk posttreatment. Control effectiveness varied considerably across NSMAD, with Natular XRT failure levels not exceeding 25% out to 12 wk (84 days) and VectoLex FG failure levels not exceeding 9% out to 8 wk (56 days) in zone A operational areas in the northern third of the district, while the zone B and zone C areas showed progressively higher levels of control failure farther to the south. This may be associated with the relative age of the stormwater management systems (generally older to the south) or the relative density of housing (generally higher to the south), but the specific characteristics that make effective control more difficult to achieve in the southern range of the district are unknown and require further investigation. It should be noted that the experimental study was conducted in neighborhoods located in the zone B and zone C operational areas, which likely influenced the durations of control that were observed in the experimental study.

The primary objective of this study was to provide data to support decisions about product selection and treatment frequency for effective and economical catch basin mosquito control. Based on the cost of a single treatment round, it appears that a product like the granular VectoLex FG would provide a more economical and effective alternative to extended-duration products that cost more per dose, even if multiple reapplications of the less expensive product are required. In reality, given the local variations we have observed, a protocol consisting of single applications of extended-release formulations in areas where they provide adequate control coupled with repeated applications of shorter-duration products in areas that are more difficult to control may allow more cost-efficient use of field technician staff time and produce optimal control results overall.

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