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AGDISP REFINEMENT STUDY: REPORT ON THE AERIAL PESTICIDE APPLICATION SURVEY AND SUBSEQUENT TREATMENT CHOICES

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ABSTRACT. This paper highlights findings from a targeted survey of aerial pesticide applicators who specialize in mosquito control space sprays. The questionnaire captured location and site details, aircraft types, and use scenarios, as well as spray system configurations, operational protocols, and pesticide use. By identifying common application settings across different platforms, the survey offers a vital benchmark for ensuring that current and future gathering of empirical data for AGriculturalDISPersal™ (AGDISP) refinement aligns with real-world conditions. These data are discussed in relation to the current mechanistic model AGDISP and relevance to the design of the field trials already underway at Lee County Mosquito Control District, Florida.

KEY WORDS Aerial applications, AGDISP modernization, space spray, survey, treatments

INTRODUCTION

Mosquito adulticiding is a response to the adult mosquito population exceeding a threshold or to the identification of vector-borne disease in the region. Aerial adulticiding is a wide area space spray, producing an aerosol cloud of very small droplets suspended in the environment where the adult mosquitoes are actively flying. Droplets need to be small enough to increase the probability of contacting the flying mosquito, but large enough to impinge upon the mosquito and contain a single lethal dose (Latham and Barber 2007).

One of the most significant developments for aerial applications is the near-wake model pesticide dispersion model AGriculturalDISPersal™ (AGDISP). The wake model is a Lagrangian model that tracks the movement of spray material from nozzles at the aircraft until they either deposit or drift downwind (Bonds 2012). To date AGDISP model development has examined and incorporated several aspects specific to mosquito control (Teske et al. 2024). Release heights were increased with the addition of an appropriate vortical decay rate consistent with out-of-ground effect (Teske et al. 2003). Very low application rates were permitted, as well as very large swath widths. Smaller drop size distributions were measured consistent with the typical droplet volume median diam (Dv0.5) sprayed by mosquito vector control aircraft. The AGDISP model was extended into the far field by the Gaussian extension (Teske et al. 2024).

A primary concern is that the original design emphasis of AGDISP was on open fields that reflect agricultural paradigms instead of mosquito control. Operational input parameters must be investigated to better reflect how and where wide-area mosquito adulticide applications are conducted. The model needs to better reflect the effect of the surface vegetation and obstructions on spray dispersal, dilution, degradation, and ultimately removal of the pesticide.

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Since the original development of AGDISP computing technology, agricultural practices, and regulatory demands have advanced dramatically. We now have an unprecedented opportunity to build on AGDISP's strong scientific foundation and transform it into a next-generation, open-source tool that meets the needs of agriculture forestry and mosquito control.

The American Mosquito Control Association (AMCA) secured a grant to provide empirical data for the refinement of the mechanistic model, AGDISP. The aim is to gather empirical data on the distribution of residues from operationally relevant applications in heterogeneous environments to predict potential impacts on nontarget organisms. The empirical data gathered will be used to underpin development of a refined model to simulate spray deposition and drift from aerial adulticide applications. The AGDISP modernization project (AMP) was initiated by the US National Agricultural Aviation Association with Stephen Foster (Foster & Associates Consulting Group Inc., Ontario, CA) performing the actual modification of the software. Experts from each end use are collaborating on the project. The AMCA leads the effort to gather data for mosquito control. The USDA Agricultural Research Service Aerial Application Research Unit, and Scion, the New Zealand Forest Research Institute, represent agriculture and forestry applications. There is considerable interest in unmanned vehicles bringing onboard collaborators from the Organisation for Economic Co-operation and Development Drone sub-group of the Working Party on Pesticides and Unmanned Aerial Pesticide Application System Task Force initiative. There is international agreement that the current AGDISP model, while good for what it was designed for, requires updating. The modernized spray model would leverage the existing AGDISP model to the extent practical while overcoming some of the simplifying assumptions to improve the model's utility. The model needs to reflect the effect of the habitat on spray dispersal, dilution, degradation, and ultimately removal of the pesticide.

The primary objective of the work discussed in this report is to gather data to validate model development and to facilitate the assessment of drift based on

Table 1. AMCA survey requesting information on operational practices for aerial adulticiding.

Demographics	What is your organization's name and location?	• Organization Name: • Your Name: • Organization Location:
Platform	What aircraft type (make and model) do you use for adulticide operations? (If you use a contractor, what type do they fly?)	• Application altitude
Products	What type of product do you use?	
	If you commonly use a diluent, please specify what you dilute with	
	What is your average or typical application rate for the products if used?	
Equipment	What is your aircraft's atomizer type, boom pressure, rpms, and flow rate?	• Atomizer Type: • Boom Pressure: • RPMs: • Flow Rate:
	What adjustments, if any, are made to the nozzles to ensure appropriate droplet sizes?	
	Where on the aircraft are the nozzles located?	
The application	What is your typical swath width for adulticide applications?	
	When is your application start time?	
	Do you use meteorological equipment on the aircraft or on the ground?	
	What are the average number of aerial adulticide application events per year?	
	What is an average acreage treated per aerial adulticide application event?	
	Can you describe the typical land use cover of your adulticide sites (farm areas, open field, wooded, marshes, suburban, urban, etc.)?	

changes in meteorology, application method, and local surface conditions. The AMCA conducted a survey to gather operational data on mosquito adulticide space sprays with the intent to guide field evaluations. The survey collected data on location, site description, aircraft type, and use scenarios along with spray system description, operational protocols, and pesticide use information. These data were used to ensure that the AGDISP refinement study employed operationally relevant settings.

The data generated from this project will provide an empirical database on spray dispersion characteristics. The database will help local districts communicate the impacts of their applications to residents and improve application efficiency, all of which should help expand the public's education on the utility and efficacy of wide-area mosquito control applications. By understanding how aerial applicators typically conduct aerial applications, the treatment structure can mirror real-world conditions. This approach increases the relevance and credibility of the findings for mosquito control professionals and policymakers alike, ultimately guiding more evidence-based regulations and best management practices.

METHODS

A survey was sent out to the AMCA membership in July 2023 to determine and assess aerial adulticide application practices in the United States (Table 1). The survey included 14 questions divided into 5 sections: demographics, the platform, products, equipment, and application settings. Data collected from the survey were gathered and imported into an Excel spreadsheet for analysis (Microsoft, Redmond, WA). The analysis consisted of counting and or averaging the responses.

RESULTS

There were 27 responses in total with 6 of the respondents using an aerial service provider and 21 maintaining their own aircraft. Two of our survey questions, 1 asking whether operators diluted their spray mixtures and another inquiring about the position of the atomizer on the aircraft, received notably low or incomplete response rates. Respondents may have found these questions either unclear, too technical, or outside the routine practices they were comfortable reporting. Consequently, data for these specific items were insufficient to draw firm conclusions. Most space spray applications do not use diluents especially with organophosphates, but some of the pyrethroids do get diluted, and indications that a diluent was used can be seen with higher application rates, e.g., 140–350 ml/ha (2 and 5 oz/ac). The nozzle location information is a detailed question requiring information in relation to the centerline of the aircraft. Unfortunately, only 2 respondents understood this. More information should have been provided to help respondents answer correctly. Most answered the nozzle location question with a general area (e.g., under wings), and 2 respondents provided useable distances from the fuselage. During the field evaluations the nozzle location will be appropriately recorded so the systems can be effectively entered into the AGDISP model.

Respondents were mostly from coastal states (Fig. 1): 7 from Florida, 4 from Louisiana, and 6 from California; all other states had just 1 respondent. All respondents utilized manned aircraft. Unmanned aircraft are primarily utilized for larviciding operations, while adulticiding with unmanned aircraft is limited and currently supported by a single contractor operating in approximately 5 states (FL, LA, WA NV, and UT; Reynolds, personal communication).

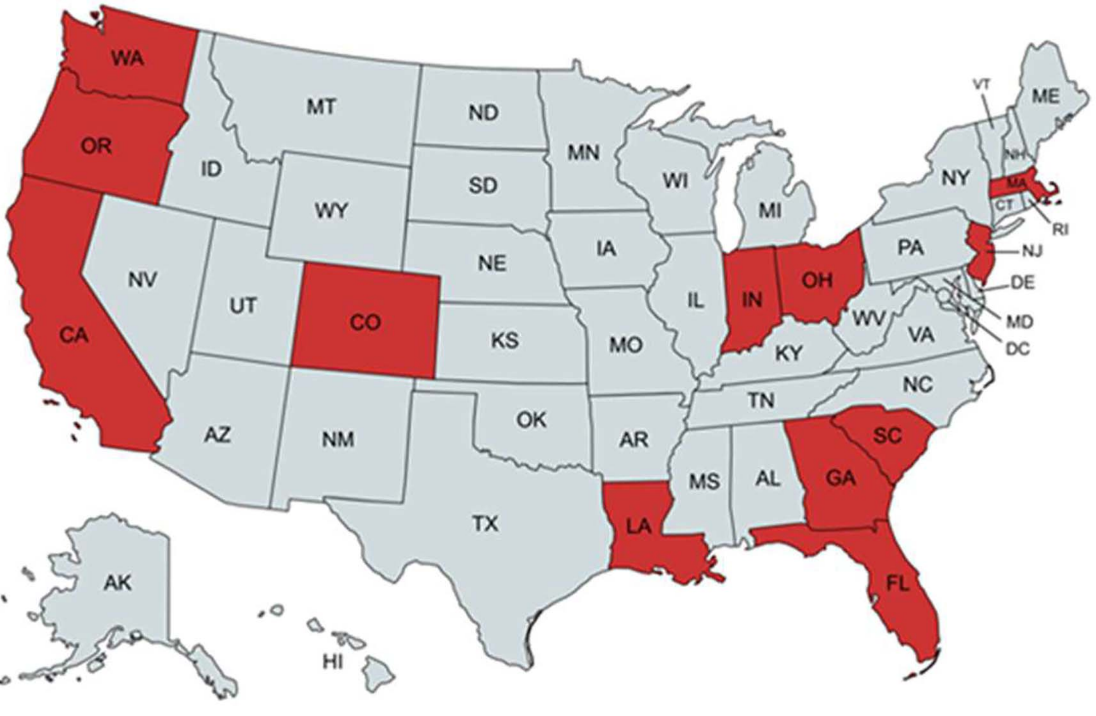

Fig. 1. States that were represented by survey respondents.

Florida is 1 of the most active states for spraying mosquito adulticides by air, followed by California. To ensure that the data gathered for the AGDISP refinement study are nationally relevant, field trial sites have been chosen across diverse geographical areas The 3 different locations will provide distinctly different environmental and atmospheric conditions.

FLORIDA (RURAL ENVIRONMENT)

- Climate and weather conditions: Florida is characterized by a humid subtropical climate with high humidity, frequent rainfall, and warm temperatures. In rural areas, vegetation and water bodies like lakes or wetlands are common, contributing to local moisture and temperature variations.
- Energy balance: High latent heat flux from soil and vegetation (due to evaporation and transpiration) is significant, influencing the energy balance by reducing temperature gradients.
- Impact on spray: The high humidity and frequent calm conditions in Florida may reduce the horizontal dispersion of the spray due to lower turbulence.

CALIFORNIA (URBAN ENVIRONMENT)

- Climate and weather conditions: Urban areas in California, particularly in the coastal and inland regions, can have a Mediterranean climate characterized by warm, dry summers and mild, wet winters. Cities are prone to heat islands, where the temperature is higher than in surrounding rural areas.
- Energy balance: Urban areas typically have low latent heat flux and higher sensible heat flux due to concrete, asphalt, and less vegetation.
- Impact on spray: Strong inversions may be observed due to the rapid cooling of the surface, which may lead to a more concentrated spray. Stronger winds possibly carry the spray farther.

AGRICULTURAL PLAINS (RURAL/FLAT ENVIRONMENT)

- Climate and weather conditions: The Southern Plains are characterized by a continental climate with distinct seasons, including hot summers and cold winters. The plains are generally flat, with little topography to interrupt wind flow, making the region more prone to high wind speeds and consistent wind patterns.
- Energy balance: With more agricultural land, evapotranspiration from crops and fields contributes to a substantial latent heat flux. During the growing season, this can moderate temperature variations, while fallow or harvested fields may cause more sensible heat flux.
- Impact on spray: The strong winds and flat terrain of the Plains states may result in higher horizontal dispersion of the spray. However, stable night conditions may limit vertical dispersion, causing the spray to remain concentrated closer to the ground at night.

Vegetation effect: One of the concerns within the mosquito control community is that the AGDISP model is not being used in a way that properly portrays operational practices. The main issue is that in using AGDISP, risk assessment modelers enter "none" in the "Surface/Canopy" section, which means that the majority of the applied product will deposit to the ground without encountering vegetation or some other obstacle that can filter the spray. With the canopy turned off, AGDISP will still allow droplets to evaporate (especially <30 μm), mix upward, and be carried away by turbulent diffusion (Teske et al. 2003), and move laterally outside of the receptor grid. Evaporation is highly relevant to the agricultural and forestry community, less so to mosquito control as relatively nonvolatile compounds are sprayed. Currently AGDISP treats the active ingredient as chemically stable over the modeled period, and there is no decay term for active ingredient concentration due to photolysis, hydrolysis, or oxidative degradation.

The AGDISP refinement study will be nationally relevant and provide data on operationally germane sites showing the spray dispersion characteristics in both an open field and a location that has obstructions that filter the spray. The data-gathering exercise began in Florida supported by Lee County Mosquito Control District. Finding sites that could accommodate the 2 km sample line was challenging. The open field site is a cattle ranch, and the obstructed site is a wildlife management wetland refuge.

Meteorology: Meteorological measurements are critical to all forms of pesticide application, but they are especially important for space sprays, where ultra-fine sprays are released from relatively high altitudes, increasing susceptibility to atmospheric turbulence and wind drift. Accurate characterization of wind speed, direction, temperature, humidity, and atmospheric stability is therefore essential to predict droplet fate and ensure both efficacy and environmental safety Within the survey the methods for measuring the meteorology at time of application were queried. All respondents took some measure of meteorology; 7 were ground measures and the other 20 had a meteorological sensor on the aircraft. Most used is an aircraft integrated meteorological measurement system (AIMMS).

Wind speed and direction are critical for determining how spray drifts and where it deposits. AGDISP uses a simplified boundary-layer approach (employing power law or log-profile equations) to adjust and apply wind speeds measured at 1 or more reference heights up to the actual spray release height. Twenty of the 27 respondents may enter their own profile of the wind up to application attitude within the model. The other meteorological inputs are the following:

- Temperature: This affects evaporation rates of droplets, particularly smaller ones, which can evaporate faster in higher temperatures.
- Humidity: Relative humidity influences evaporation as well. Low humidity leads to quicker evaporation, reducing the droplet size.
- Stability of the atmosphere: AGDISP accounts for atmospheric stability (e.g., stable, neutral, or unstable conditions) to model vertical and horizontal dispersion of the spray.

Future developments with AGDISP are looking to expand the model both spatially and temporally, essentially a four-dimensional model. The aim is to have detailed meteorological measures at altitude preferably with an AIMMS system as an established method for meteorological data collection (McLeod et al. 2012). An AIMMS system was not available for this first round of testing, so wind speed and direction were collected with a meteorological drone (Astro Freefly Systems, Woodinville, WA) at the application altitude during the application. In addition, 6 meteorological stations positioned at 0, 1 km, and 2 km record conditions as the spray plume dissipates downwind. At 0 km (the spray line) the meteorological towers were equipped with 2 three-dimensional sonic anemometers (RM Young) at 2 and 4 m. Temperature humidity and barometric pressure are also measured along with energy balance measured with a net radiometer. At 1 and 2 km the stations had 1 sonic anemometer and 1 net radiometer at 2 m AGL.

Aircraft type: Of the aircraft used for space spraying, 75% were fixed wing and 25% were helicopter platforms. To populate the AGDISP model various information must be gathered on the aircraft itself: weight of aircraft, wing semispan, speed, and release height. The nozzle location is important and defined in the model by the number, vertical offset, horizontal offset, boom width, and nozzle spacing. All this information will be entered into AGDISP and saved for later use. The reported fixed wing airframes, their weight, and the cruise speeds are provided in Table 2 to show the range of platforms used. The reported helicopters used for space spraying are given in Table 3. The aircraft speed during application depends on the desired application rate, flow rate, and swath width. These tables simply provide a comparator between the different aircraft. During the field evaluations, aircraft speed will be recorded and fixed throughout the trials.

No single aircraft type appeared to be standard. Piper aircraft were the most represented, but this is because they are the aircraft used by 1 of the aerial application services. Using 1 of the larger fixed wings such as a Douglas C47 or a C130 would not be representative of a typical fleet vehicle, but otherwise there is not a constraint on aircraft type.

Within the AGDISP model, there is an extensive aircraft library that will define the wake turbulence effects on spray drop dispersal of different aerial platforms and different nozzle/boom placements. At

Table 2. Fixed wing aircraft reported in survey their, weight, cruise max speed, release height, and semispan.

Fixed wing	Max take-off weight (kg)	Cruise/max speed (m/s)	Release height (m)	Semispan (m)
Air Tractor AT-402	4,159	71.5	61	7.7
Brittan Normand Islanders	2,993	62.5	91.4	7.5
Beechcraft King Air 90	4,755	98.3	91.4	8.2
Beechcraft King Air 200	5,699	129.6	91.4	8.2
C130	70,306	167.2	91.4	20.1
Cessna 188	1,496	53.6	30.4–91.4	6.4
Cessna 337	2,100	78.2	45.7–61	5.9
DHC-6-100	5,669	76	91.4	9.9
Douglas C47	14,061	82.7	91.4	14.5
Gruman AgCat	3,184	58.1	61	6.4
OV-10 Bronco	6,551	98.3	61	6.1
Piper Navajo Chieftain	2,948	78.2	122	6.1
Piper Aztec	2,177	80.4	91.4	5.6
Shorts SC7 Skyvan	5,669	76	91.4	9.9

low-release altitudes 6 m (<20 ft) above ground level (AGL) the wingtip vortices and prop wash dominate the droplet movement. At 30.5 m (>100 ft), these vortex structures tend to dissipate before getting close to the target. That said, the spray aircraft type, crosswind speed, and atmospheric stability are the most important physical parameters (Teske et al. 2024). Ideally the platform types should remain equal, within a treatment. If, however, getting the same application aircraft is not possible when moving between states, a sensitivity analysis with the model will allow analysis of equipment disparities.

Pesticide information: The most common adulticiding compound was reported to be naled (Dibrom) with 76% of the respondents using this product, followed by pyrethroids at 24%. The application rate of naled was listed at a minimum of 32.2 ml/ha (0.46 oz/ac) and a maximum of 68.6 ml/ha (0.98 oz/ac) and a mode of 52.5 ml/ha (0.75 oz/ac). The pyrethroids were applied at a minimum rate of 12.6 ml/ha (0.18 oz/ac) and a maximum rate of 350 ml/ha (5 oz/ac), which indicates a diluent was used, and a mode of 70 ml/ha (1 oz/ac). Malathion was applied at a minimum of 46.2 ml/ha (0.66 oz/ac) and a maximum of 140 ml/ha (2 oz/ac), and pyrethrum at 140, 45.5, 56, 59.5 ml/ha (2, 0.65, 0.8, and 0.85 oz/ac).

The size of the area treated with fixed wing was reported to be a minimum of 809 ha (2,000 acres) and a maximum of 161,874 ha (400,000 ac) with an average of 4,572 (11,298). In general, the fixed wing applications covered larger areas that were described as wooded marshes and suburban. Helicopters tended toward a lower number of acres sprayed with a maximum of 5,260 ha (13,000 acres), with the areas sprayed described as urban and suburban.

The AGDISP accounts for the impact of different pesticides primarily through density and evaporation parameters. The specific gravity and the volatile fraction are the most influential fluid properties, affecting droplet settling and mass loss over time. Ultimately, droplet size (combined with these properties) dictates how far droplets drift, how quickly they deposit, and how much pesticide mass remains in each droplet upon reaching the target (Teske et al. 2011). Within this space spray project, it was decided that a surrogate oil would be used to minimize environmental contamination and simplify the process by using a nonvolatile compound. The surrogate chosen was BVA 13 oil (Azelis, Shreveport, LA) as it has a specific gravity similar to synthetic pyrethroids and is used operationally as a diluent for space sprays.

Application: For fixed wing applications all but 3 of the respondents utilize AU4000, 2 respondents use Zanoni rotary atomizers, and the C130 uses the electric-driven AU6539. For helicopters rotary atomizers are also utilized, but the electric-driven AU6539 are preferred with 1 group using the wind-driven AU4000. For fixed wing aircraft the

Table 3. Helicopters aircraft reported in the survey their empty weight, max cruise speed, release height, and semispan.

Helicopter	Max take-off weight (kg)	Cruise/max speed (m/s)	Release height (m)	Semispan (m)
Airbus H125	2,249	62.5	30.5–61	5.3
Bell 206	1,360	53.6	61	5
Bell 407	2,721	67	61	5.3
Bell UH-1	4,762	58.1	61	7.3
MD-500	1,360	96.3	50.2–45.7	3.9

Table 4. The average application settings from the survey defining the application settings (treatment) for each of the 3 platforms.

Platform	Type	Flow rate liters/min	Speed (m/s)	Altitude (m)	Semispan (m)	Weight (kg)
Helicopter	Airbus H125	5.2	51.4	53.3	5.3	2,585
UASS	PV40X	0.1	3.4	38.1		
Fixed wing	King Air 90	7.6	67	76.2	8.2	4,535

application altitude from 26 responses showed a minimum of 45 m (150 ft) AGL and a maximum of 122 m (400 ft) AGL with a mode of 91 m (300 ft) AGL. Only 7 of the 26 of the responses deviated from 91 m (300 ft) AGL. For helicopters there were only 7 respondents with a minimum of 30 m (100 ft) AGL and a maximum of 61 m (200 ft) AGL and a mode of 61 m (200 ft) AGL. The 30 m (100 ft) altitude was from the Florida Keys, which must target small islands as opposed to the wide areas otherwise targeted by these applications. The average application altitude was 53 m (175 ft) AGL for helicopters and 76 m (250 ft) AGL for fixed wing.

With fixed wing the minimum swath width was 152 m (500 ft) and the maximum 610 m (2,000 ft), and the mode was 305 m (1,000 ft), with 20 out of 28 responses reporting that distance. With helicopters there was a smaller group of respondents with more variation in operational practices; 1 at 152 m (500 ft), 213 m (700 ft), and 274 m (900 ft) and 4 respondents at 305 m (1,000 ft). The swath widths correlated with the application rates.

Fundamentally, AGDISP is what is known as a line source model. This means that the model actually performs calculations based on the amount of material that is released on a given length of flightline (typically expressed as liters/m). To arrive at this number, in the default scenario, AGDISP uses the application rate, typically entered as vol/area (liters/m^2) and the swath width to arrive at liters/m. This internal calculation is responsible for some issues in AGDISP, which are exacerbated in mosquito control because the swath widths are typically 10 times or more wider than what they are in most other types of pesticide application. To avoid this problem, AGDISP allows the user to directly enter application rate as vol/time (liters/s) and uses aircraft speed to arrive at the units (liters/m) that the model requires. This is the approach used in the studies being discussed.

Within the survey the average fixed wing flowrate was 256 oz/min (P90 348 oz/min and P50 268 oz/min), and the average helicopter flowrate was 174 oz/min (P90 202 oz/min and P50 160 oz/min). Within this study we adjusted flow rate to fit the average found in the reviews the increase in flow with the fixed wing representing the increase in forward speed. Table 4 provides the current aircraft settings used in the trials in Lee County Mosquito Control District, Florida. These settings will be followed as closely as possible in the other states.

DISCUSSION

This report provides a breakdown of the operational practices reported within a survey for the AMP. That information has been used to define operationally relevant treatment parameters for the current effort to gather empirical data. This is an international effort aimed at evolving AGDISP into model that more accurately supports precision pesticide application.

Agencies conducting area-wide mosquito control, regardless of whether it is fixed wing, helicopter, or UASS, consistently demonstrated compliance with label directions and best management practices. This ensures the mission has the desired effect of reducing the adult mosquito population below established threshold values. Thresholds that protect the public health from circulating pathogens and/or improve quality of life from an overabundance of adult biting mosquitoes. While this report was able to identify the habitat and general area (state or agency within a state), further transparency is needed to allow for outside regulatory agencies to better understand precisely where the missions occur. This information is available at the local agency, but it is very cumbersome to currently collect and provide to regulatory agencies such as the Environmental Protection Agency, U.S. Fish and Wildlife Service, and National Marine Fisheries Service. A national database that collected such information and made it available to these agencies would help enhance risk management decisions. The AMCA has been working on creating a consensus from participating agencies to collect this data, along with other relevant application parameters, and is striving to further refine the AGDISP model and our understanding of the impact of our members' mosquito control applications.

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