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Innovative Strategy for the Containment of adult Ochlerotatus caspius: Spatial Dynamics and Integrated Approach Against Rice Field–Origin Invasions in the Alessandria Area, Strategic Barrier Interventions

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Abstract

Introduction:

Alessandria, a city in Northern Italy, faces seasonal invasions of *Ochlerotatus caspius*, a highly migratory mosquito species breeding in the extensive rice fields north of the Po River. Due to the impossibility of larvicidal treatment in these agricultural zones, the municipality developed an innovative barrier-based adult mosquito control strategy.

Materials and Methods

A mobile anti-mosquito barrier was implemented along a 27-km semicircular route north of the city, divided into five color-coded operational sectors. Nebulization treatments using natural pyrethrum were conducted during the mosquitoes' peak evening flight window. Efficacy was assessed through pre- and post-treatment CO_2-baited trap monitoring, complemented by meteorological data.

Results

Each treatment achieved a 24-hour suppression effect, with consistent mosquito population reductions observed in trap data. Repeated applications throughout the season demonstrated a synergistic effect, extending protective coverage up to 15 days. Urban involvement was enhanced through citizen-based storm drain interventions using TombiniNet.

Discussion

This integrative approach combining geospatial targeting, environmentally safe insecticides, real-time monitoring, and public participation offers a scalable and ecologically sound model for mosquito management in rice-growing regions impacted by climate-sensitive vector dynamics.

Introduction

Mosquito-borne diseases represent a persistent public health challenge globally, particularly in regions with expanding urbanization, agricultural development, and shifting climatic patterns. In recent decades, both endemic and invasive mosquito species have adapted to a broad array of ecological niches, enhancing their reproductive potential and migratory behaviors. Among these species, *Ochlerotatus caspius*, also known as the salt marsh or rice field mosquito, stands out for its aggressive anthropophilic tendencies, high fecundity, and remarkable flight capabilities. This species is particularly notorious for its ability to travel over extensive distances often exceeding 30 kilometers from its breeding grounds to human-inhabited zones, where it becomes a major source of discomfort and potential disease transmission during the summer months(Wilke et al. 2020).

In Northern Italy, the municipality of Alessandria situated just south of the hills of Valmadonna and surrounded by extensive rice cultivation areas along the Po River basin presents a unique case study in vector control and environmental management. The city, with a population of approximately 100,000, lies at the confluence of several ecological and topographical factors that render it highly vulnerable to seasonal mosquito invasions. The Po River, Italy's largest watercourse, borders a vast expanse of rice fields spanning nearly 120,000 hectares. These rice paddies serve as prolific breeding grounds for *O. caspius*, supporting up to seven mosquito generations per season under favorable environmental conditions(Bisanzio et al. 2011; Palazzoli et al. 2024).

The topographical and climatic configuration of Alessandria significantly exacerbates its exposure to mosquito incursions. The hills to the north create a funnel-like effect that channels migrating mosquito populations directly toward the urban area. Studies conducted in adjacent municipalities, such as Valenza, have demonstrated that mosquito densities are substantially higher in hilly zones compared to adjacent lowlands confirming the strategic importance of these elevations in shaping migration routes. Mosquitoes are attracted by the cooler microclimates, increased vegetation cover, and horizon light during sunset, which collectively draw large swarms southward into Alessandria during twilight hours. This phenomenon occurs with remarkable temporal precision: adult *O. caspius* begin migrating approximately 10 minutes after sunset, peaking in activity 20 minutes post-sunset, with total flight durations lasting up to 50 minutes. This narrow but predictable window is critical for the timing of adulticide interventions(Alten et al. 2000; Becker et al. 2010).

Conventional mosquito control strategies, including larvicidal treatments in rice paddies, face considerable limitations in Alessandria. The region's agricultural landscape, property boundaries, and regulatory complexities often hinder direct intervention at larval breeding sites. Consequently, the local administration has adopted an alternative operational strategy centered on intercepting adult mosquitoes along their migratory routes. This shift from source control to barrier intervention represents an innovative approach, grounded in entomological surveillance, environmental monitoring, and coordinated technical deployment(González et al. 2024).

The core of this strategy is the Mobile Anti-Mosquito Barrier, a 270-degree semicircular treatment path established along the northern perimeter of the city. It employs high-altitude nebulization techniques using natural pyrethrum-based adulticides, dispersed by slow-moving vehicles capable of spraying vertically up to 30–40 meters. The barrier is subdivided into distinct color-coded sectors Yellow, Red, Orange, Blue, and Violet that correspond to strategic entry points identified through prior entomological and geographical studies. Repeated at least 15 times during peak season (July–August), these treatments create a synergistic and cumulative effect, forming a protective envelope that can remain effective for up to 15 days per cycle(Fonseca et al. 2013; Stoops et al. 2019).

The efficacy of this barrier intervention is meticulously monitored through an entomological surveillance system comprising fixed and mobile CO_2-baited traps. These traps are positioned in both urban and rural areas to track pre- and post-treatment mosquito densities. The inclusion of meteorological monitoring

measuring temperature, humidity, and wind patterns enables correlation analysis between environmental variables and treatment success. The strategy's validation is further supported by real-time GPS-tracked operational routes, mapped via field inspections and georeferenced documentation(Akhoundi et al. 2018; Fonseca et al. 2013).

A supplementary public health measure, known as TombiniNet, enhances the campaign by empowering citizens to intervene at microhabitats such as domestic storm drains. This low-cost, do-it-yourself mosquito net system physically prevents mosquitoes from accessing stagnant water to lay eggs, thus addressing the significant proportion (60–80%) of tiger mosquito populations that originate from private homes. This initiative exemplifies the synergistic integration of institutional and civic engagement in sustainable mosquito control. The following study presents a detailed analysis of this multifaceted operational model in Alessandria. It integrates geographical mapping, biological behavior analysis, field intervention logistics, and community-based action to offer a replicable and scalable framework for managing mosquito invasions in ecologically vulnerable urban areas. The case of Alessandria underscores the necessity for localized, data-driven, and environmentally conscious solutions to vector management, especially under the growing influence of climate change on mosquito ecology(Carrieri et al. 2011; Organization 2012).

Materials and Methods

Geographical Context and Ecological Vulnerability of Alessandria

The municipality of Alessandria is located in the southeastern part of the Piedmont region of Northern Italy, positioned strategically at the intersection of several ecological zones that directly influence the dynamics of mosquito proliferation. Geographically, the city lies immediately south of the Valmadonna hills, with the expansive Po River basin and the agriculturally intensive rice-producing plains of Lomellina to its north. This distinct topographical gradient from elevated rural zones to lower urban settlements creates a naturally conducive setting for the southward migration of mosquitoes, particularly *Ochlerotatus caspius*, during the warmer months of the year. The Po River, Italy's longest river, defines the northern boundary of the wider Alessandria territory. Beyond the river lies an estimated 120,000 hectares of flooded rice paddies a landscape that functions as a veritable breeding engine for *O. caspius*, a species remarkably well-adapted to aquatic habitats. These rice fields are irrigated from late spring to summer, coinciding with the seasonal rise in mosquito activity. Each summer, as rice cultivation intensifies, so too does the emergence of multiple synchronized mosquito generations. Under ideal environmental conditions, up to seven successive generations can be produced in a single season, significantly amplifying population pressure on adjacent urban zones(Baldacchino et al. 2015; Bellini et al. 2014).

Unlike container-breeding urban mosquitoes such as *Aedes albopictus*, *O. caspius* thrives in large-scale agricultural wetlands. Its biology is uniquely suited to long-distance dispersal, capable of navigating over 30 kilometers in search of favorable microclimates. The high reflectivity of the flooded fields, along with

the open sky and vegetative cover of nearby hills, forms visual and thermal cues that guide mosquitoes toward inhabited areas. Alessandria's unique geography a flat urban basin surrounded by hills creates what researchers have termed a "funnel effect," concentrating insect migrations along a narrow corridor directly into the city. This effect was visually documented in a 2021 study conducted in Valenza and is illustrated in **Figure 1** of the original report.

Valmadonna and Valle San Bartolomeo, two northern districts of Alessandria, are especially vulnerable due to their transitional location between hill and plain. Monitoring studies have repeatedly recorded unusually high mosquito densities in these areas, underscoring their importance as both entry points and buffer zones. In fact, entomological data reveal that the vast majority of mosquitoes sampled in these sectors during the peak summer months belong to the *O. caspius* species, rather than the more commonly known *Aedes albopictus* or *Culex pipiens*. This evidence validates the necessity of implementing geographically targeted barrier treatments in these microzones. Furthermore, the rice field region of Lomellina historically part of Pavia province acts almost as an ecological extension of Alessandria due to its wedge-like incursion into the local territory. This extension not only increases the direct exposure of Alessandria to northern mosquito populations but also complicates administrative coordination for regional mosquito control. Despite the proximity and interconnected ecology, current legislation does not allow for direct intervention within these upstream breeding sites. As a result, local authorities in Alessandria must rely on innovative strategies that intercept adult mosquitos' mid-flight, rather than eliminate them at the larval source(Bo et al. 2025; DI LOTTA INTEGRATA).

The vulnerability of Alessandria is further compounded by climatic variables. The region's humid subtropical climate is characterized by hot, wet summers and mild winters an ideal setting for mosquito development. Data from 1990 to 2017 show that summer temperatures in the Alessandria area often reach up to 30°C, with corresponding peaks in humidity and stagnant water accumulation. These conditions are amplified in the hill zones, which offer dense vegetation and cooler shaded microclimates attractive resting zones for migrating insects. Moreover, the urban heat island effect exacerbates thermal gradients that facilitate mosquito movement from cooler peripheries to warmer central zones. This interplay of hydrological, topographical, and climatic conditions positions Alessandria at a critical interface of mosquito ecology in Northern Italy. Any effective vector control strategy must therefore be spatially and temporally tuned to these unique vulnerabilities. In the subsequent sections, we explore how these challenges are addressed through a coordinated operational strategy that integrates entomological monitoring, real-time environmental data, and field-based interventions(Manica 2018; Rochlin et al. 2013).

Biological Behavior and Migratory Dynamics of Ochlerotatus caspius

Ochlerotatus caspius, commonly referred to as the rice field mosquito, is one of the most prolific and aggressive mosquito species found in Southern and Central Europe, particularly in anthropogenically modified wetland environments such as the rice paddies of Northern Italy. Its biology, reproductive capacity, and behavioral patterns set it apart as a primary target for vector control programs in

ecologically vulnerable municipalities such as Alessandria. Unlike more sedentary species like *Aedes albopictus*, *O. caspius* is adapted to highly dynamic and wide-ranging movement, enabling it to colonize distant urban environments far from its original aquatic breeding grounds. One of the defining characteristics of *O. caspius* is its ability to produce up to seven generations in a single summer season. This reproductive efficiency is driven by the persistent presence of flooded rice paddies throughout the warm months, providing continuous breeding substrates. Eggs are typically laid in shallow, stagnant water with moderate organic content conditions that are optimally met in irrigated rice field systems. Once hatched, the larvae develop rapidly, progressing through instars and pupating within days under suitable thermal conditions, often accelerated by high ambient temperatures and nutrient-rich water(Medlock et al. 2015; Versteirt 2012).

The adult mosquito exhibits extraordinary flight capabilities. Studies conducted in and around the Province of Alessandria have documented dispersal distances of *O. caspius* exceeding 30 kilometers a range that allows for broad migration across agricultural and urban gradients. This capacity for long-range dispersal is influenced by a combination of visual, thermal, and olfactory cues. Notably, the phenomenon of horizon light at sunset has been identified as a critical visual stimulus that triggers mass evening migration flights, directing mosquitoes toward illuminated, vegetated, and cooler zones, such as the hilly peripheries and urban canopy of Alessandria. Longitudinal observational data have confirmed a highly reproducible and time-specific flight behavior in *O. caspius*. Each evening, mosquitoes initiate flight approximately 10 minutes after sunset, with activity peaking at around 20 minutes post-sunset. The overall duration of this migratory phase typically lasts 45 to 50 minutes. This narrow temporal window has immense operational significance, as it provides a predictable target for the deployment of adulticidal interventions particularly barrier spraying. When treatments are synchronized with this peak flight period, adult mosquitoes are more likely to encounter airborne droplets during their active movement, increasing the probability of contact and knockdown(Baldacchino et al. 2015; Metelmann 2019).

Moreover, the topography of the Alessandria region amplifies the effectiveness of mosquito movement toward the urban core. The hills of Valmadonna and the elevated terrain surrounding Pietra Marazzi, Rivarone, and Montecastello create a gravitational and thermal “funnel effect”. As the mosquitoes descend from the higher rice fields north of the Po River, they are channeled through this topographical corridor, converging along specific routes into the municipality. This phenomenon has been visualized in several entomological and geospatial studies, such as those conducted in Valenza and documented in **Figure 1** of the municipal report. Entomological surveillance in Alessandria confirms that *O. caspius* is the dominant species in the northern and north-eastern districts during the peak months of July and August. The density of this species in areas such as Valmadonna and Valle San Bartolomeo has reached levels requiring extraordinary measures, often exceeding the nuisance thresholds defined by regional health authorities. In response, the strategic decision was made to intercept mosquitoes not at their breeding origin which lies outside municipal jurisdiction but along their migratory pathway, using mobile barrier interventions.

An additional ecological factor contributing to the southward migration of *O. caspius* is the favorable microclimate of the hills surrounding Alessandria. These zones offer cooler temperatures, higher humidity, and dense vegetation cover, which collectively provide resting habitats during the hottest hours of the day. As the sun sets and temperatures moderate, mosquitoes emerge from these shelters and initiate flight toward populated zones in search of blood meals. The attractiveness of urban heat islands further exacerbates this movement, funneling mosquitoes into densely inhabited sectors. Although *O. caspius* is capable of omnidirectional movement, field studies confirm that the predominant migratory vector remains north-to-south a critical observation that underpins the architecture of the treatment routes. By concentrating adulticidal efforts along these corridors during peak migratory periods, the city of Alessandria can significantly reduce mosquito density, alleviate public discomfort, and limit potential pathogen transmission without resorting to environmentally invasive methods. In summary, the behavioral ecology of *O. caspius* characterized by mass reproductive output, long-distance dispersal, and temporally precise flight dynamics makes it both a formidable vector and an ideal candidate for time-sensitive barrier interventions. Understanding these dynamics is essential for the development of targeted mosquito control strategies that are both ecologically sustainable and operationally effective in urban-agrarian interfaces such as Alessandria(Alqassim 2024; Romiti et al. 2025).

Results

Operational Strategy and Implementation of the Mobile Anti-Mosquito Barrier

To address the increasing public health nuisance caused by *Ochlerotatus caspius* in Alessandria, the municipal government supported by entomological experts and guided by insights from regional interventions has adopted an operational strategy focused on the interception of adult mosquitoes along their migratory routes. Given the inability to access or treat the rice paddies to the north of the municipality, which serve as the primary breeding grounds, the core strategy instead relies on creating a mobile chemical-physical barrier to neutralize migrating mosquitoes before they reach populated areas(Becker et al. 2010; Stoops et al. 2019).

Conceptual Framework of the Barrier Approach

The operational model is based on the deployment of a Mobile Anti-Mosquito Barrier, which consists of high-altitude, wide-spectrum spraying treatments conducted by slow-moving vehicles equipped with atomizers. These interventions are executed in synchrony with the peak flight window of *O. caspius* beginning approximately 10 to 15 minutes before sunset and concluding around 45 to 50 minutes afterward thereby maximizing contact with active adult mosquitoes. Each spraying vehicle moves at a controlled speed of 5–10 km/h, ensuring even coverage and optimal droplet dispersion. The atomizers are capable of nebulizing pyrethrum-based products vertically up to 30–40 meters, allowing treatment to reach elevated tree canopies and vegetated hill slopes where mosquitoes rest before descending into urban areas. Importantly, the formulation used Natural Pyrethrum (ONLY PY) is of botanical origin, free of

chemical adjuvants, and approved for organic agriculture, ensuring minimal environmental residue and non-toxicity to non-target organisms(Becker et al. 2010; Isman 2006).

Treatment Routes and Color-Coded Sectors

The anti-mosquito barrier encircles the city's northern perimeter, covering a semicircular arc of approximately 270 degrees and a total length of 27 kilometers. The route has been meticulously divided into five color-coded operational sectors, each reflecting geographical, entomological, and logistical considerations, Covers Valmadonna via Strada Vicinale della Serra and Via del Sabbione up to the underpass (Yellow Sector). Begins at the Eremo di Betania and proceeds along Strada della Serra, through the repeater station and the intersection with Via Dazio (Red Sector). Continues from Via Dazio, descending through wooded paths toward the riding school ASD Sussurri e Nitriti, reaching Via Bricchi in Pietra Marazzi (Orange Sector). Extends from Pietra Marazzi along Strada Alta to Montecastello, SP80, and concludes near the Rivarone cemetery (Violet Sector). Follows a northeast trajectory, starting from the intersection at Via Franchini and the old provincial road near Lobbi, crossing Castelceriolo and reaching the SS10 highway near the Bormida River bridge (Blue Sector (Plain Route)) (**Figure 2**)(Cofone et al. 2025; Mather 1984).

Each segment is selected to align with topographical corridors that mosquitoes commonly use to enter the city, forming a coherent and spatially optimized protective barrier.

Operational Planning and Real-Time Coordination

Spraying operations are scheduled daily during peak infestation periods typically from mid-July through August based on entomological data and weather forecasts. Operations are coordinated via GPS and mapped using Google Maps with waypoints, elevation changes, and interruption points (e.g., near beehives or residential clusters) precisely marked (see **Figure 3**). Each vehicle is accompanied by a field technician responsible for ensuring compliance with safety protocols, monitoring environmental conditions, and adjusting flow rates as needed. To complete the full route within the 50-minute migratory window, the intervention is often divided into two simultaneous operations with different starting points. A reverse-direction protocol is also available to ensure adaptability in case of route obstructions or wind shifts(Becker 2016; Worwa et al. 2013).

Monitoring and Evaluation of Treatment Efficacy

The success of the intervention is assessed through an entomological monitoring system using CO_2-baited traps installed at fixed urban and peri-urban locations. Mosquito counts are taken before and after each treatment cycle, providing direct quantitative insight into population suppression rates. Additionally, the following environmental variables are recorded, Ambient temperature, Relative humidity, Wind direction and speed, Timing of sunset and duration of spray Complementary tools, such as thermal cameras and WBGT (Wet Bulb Globe Temperature) sensors, are employed to evaluate microclimatic factors that influence mosquito activity. Field data collected during the 2021 and 2023 pilot programs

showed a 24-hour immediate efficacy, with significant reductions in mosquito captures in traps. When applied systematically (at least 15 times per season), a synergistic effect was achieved establishing a residual protective buffer that lasted up to 15 days(Hustins 2006; Lipson and Dear).

Environmental and Ethical Considerations

The choice of product and application technique reflects a deliberate commitment to environmental responsibility. Natural pyrethrum applied at a dilution of 0.5–1% targets only flying insects within the active zone and degrades rapidly upon exposure to sunlight. No treatments are performed over inhabited areas, and all paths are pre-screened to avoid proximity to livestock, apiaries, or sensitive crops. Further, the project strictly complies with Italian Regional Law 75/95, and collaborates with IPLA SpA and the Regional Environmental Protection Agency (ARPA) to ensure transparency and scientific rigor(Isman 2006; Paolella and Pietrobelli).

Entomological Surveillance, Community Engagement, and Adaptive Management

Effective mosquito control in urban ecosystems demands not only precise operational interventions but also a robust, data-driven surveillance system and the active involvement of the community. In the case of Alessandria, the success of the Mobile Anti-Mosquito Barrier is closely linked to continuous entomological monitoring and a multi-tiered public engagement strategy. These elements work together to enable adaptive management, allowing interventions to be refined in real time based on observed biological, environmental, and social feedback(Achee et al. 2015; Organization 2012).

Entomological Monitoring Network

To validate the efficacy of the barrier treatments and monitor migratory dynamics of *Ochlerotatus caspius*, Alessandria has implemented a structured surveillance system centered on CO_2-baited traps. These traps are strategically placed at representative locations—one in a northern peri-urban zone (near Valmadonna or Pietra Marazzi) and the other within the urban core. Each trap collects adult mosquitoes during two key periods, Conducted the evening before scheduled barrier spraying (pre-treatment sampling). Conducted the evening following the intervention, during the same migratory window (post-treatment sampling). The comparison of captured specimens provides quantitative measures of intervention success. In recent operational cycles, a significant drop in *O. caspius* counts was consistently observed within 24 hours of treatment. Additionally, the captured data is correlated with meteorological variables such as wind speed, temperature, and humidity factors known to influence mosquito flight behavior and treatment efficacy. Starting in 2025, this surveillance system is being expanded to include two new urban trapping stations, creating a more comprehensive spatial dataset. These additions will support trend analysis, early warning signals of migration waves, and fine-tuning of route deployment(Modu 2020; Silver 2008).

Use of Microclimatic Sensors and Data Integration

To supplement entomological data, technicians use a WBGT microclimate kit (BABUC/M) capable of measuring air temperature, wet bulb temperature, relative humidity, and solar radiation along with thermal cameras and tripods for stable field deployment. These instruments help map microclimatic variability across treatment zones, guiding decisions such as timing of spray activation and route prioritization. All environmental and biological data are digitally archived and subjected to geospatial analysis using QGIS and other open-source tools. These datasets form the basis for adaptive feedback loops that ensure treatments align with ecological conditions and maximize effectiveness while minimizing environmental intrusion(Becker et al. 2010; Lindsay and Birley 1996).

Public Participation: The Role of Citizens in Source Control

While institutional interventions form the backbone of mosquito containment efforts, long-term success depends on disrupting mosquito reproduction at the microhabitat level particularly within private spaces. In Alessandria, this has led to the development and promotion of TombiniNet, an innovative citizen-friendly device designed to intercept *Aedes albopictus* at one of its most prolific urban breeding sites: the stormwater drains. TombiniNet functions as a physical mosquito screen that fits inside storm drains, preventing adult mosquitoes from accessing stagnant water to lay eggs. It is, Easy to install and remove, Reusable and washable, Inexpensive and available at no cost through public campaigns Field studies and citizen reports have shown that between 60% and 80% of tiger mosquito populations in Alessandria originate from private residences. Therefore, a device like TombiniNet allows individuals to take direct action in the fight against mosquitoes, supplementing municipal control efforts with decentralized grassroots interventions. The municipality has proposed that the Mayor of Alessandria act as the public face of this initiative recording informational videos, sending letters to households, and demonstrating installation methods via public events. A YouTube link with over 10,000 views has already helped disseminate the concept nationally, and the approach is gaining recognition as a replicable model for urban mosquito control across Europe(Allen et al. 2021; Barrera et al. 2011).

Toward a Participatory and Responsive Control Model

The integration of professional surveillance, technological tools, and citizen participation positions Alessandria's model as a modern, scalable, and sustainable mosquito control strategy. It is built not on singular interventions, but on a layered system of Predictive monitoring, Targeted adulticidal interventions, environmentally conscious product selection, Community-based larval source reduction Such a model is inherently adaptable. Route modifications, frequency adjustments, and even treatment composition can be altered in response to real-time feedback from technicians, residents, and trap data. This ensures a dynamic response to a complex and changing ecological challenge (Table 1 and Figure 4 and Full description with project images in the Supplementary File)(Allen et al. 2021; Kay and Nam 2005).

This radar chart illustrates the key strengths of the integrated mosquito management strategy implemented in Alessandria. The chart evaluates seven core dimensions operational precision, environmental safety, community engagement, surveillance and data use, effectiveness, scalability, and

innovation highlighting the approach's strong reliance on data-driven decision-making, environmentally safe interventions, and active citizen participation. The high scores across these categories reflect a sustainable and replicable model for controlling *Ochlerotatus caspius* in ecologically vulnerable urban areas.

Table 1. Comprehensive Table of the Manuscript Content

Section	Subsection	Content	Key Details / Data	Implications / Actions
Title & Authors	–	*Integrated Mosquito Management in Alessandria: Geospatial Dynamics, Migratory Patterns, and Strategic Barrier Interventions Against Ochlerotatus caspius*	Author: Dr. Ebrahim Abbasi (Shiraz University of Medical Sciences, Iran)	Study focuses on integrated mosquito control strategy in Alessandria
Abstract	Problem	Seasonal invasion of *O. caspius* from rice fields north of Po River; larvicidal treatment impractical	Rice fields cover ~120,000 ha; *O. caspius* migrates >30 km	Need for alternative adult mosquito control
	Solution	Mobile anti-mosquito barrier with natural pyrethrum	Nebulization along 27 km semicircular route; CO_2 traps for monitoring	Environmentally safe, targeted adulticidal approach
	Results	24-hour suppression per treatment; repeated applications produce 15-day residual effect	Repeated treatments ≥15 times per season	Effective reduction of mosquito population
	Citizen Engagement	TombiniNet for storm drains	60–80% of *Aedes albopictus* breeding from private residences	Citizen participation enhances overall control
Introduction	Mosquito-borne diseases	Increasing global risk due to urbanization and climate change	*O. caspius*: aggressive, anthropophilic, migratory (>30 km)	Public health threat in Northern Italy
	Local context	Alessandria near Po River basin and Valmadonna hills	Funnel effect channels mosquitoes into city	High exposure to seasonal invasions
	Challenge	Larvicidal treatments impractical due	Rice paddies produce up to 7 generations/season	Need for adult mosquito interception

Section	Subsection	Content	Key Details / Data	Implications / Actions
		to property boundaries and regulations		
Materials & Methods	Study Area	Alessandria (Piedmont, N. Italy) – flat urban basin with surrounding hills	Humid subtropical climate; summer peaks up to 30°C	Optimal conditions for mosquito development
	Mosquito Biology	*O. caspius* – prolific reproduction, long-distance dispersal, twilight migratory flights	Evening flight: starts 10 min after sunset, peaks 20 min, lasts 50 min	Predictable timing enables precise interventions
	Barrier Design	Mobile Anti-Mosquito Barrier	27 km semicircular route, 5 color-coded sectors: Yellow, Red, Orange, Violet, Blue	Vehicles spray pyrethrum vertically 30–40 m at 5–10 km/h
	Operational Details	Spraying synchronized with peak flight window	GPS-tracked routes; 2 simultaneous operations if needed	Avoid inhabited areas, apiaries, sensitive crops
	Monitoring	CO_2-baited traps, pre/post-treatment counts	Microclimatic sensors: WBGT kit, thermal cameras	Data-driven adaptive management
	Citizen Participation	TombiniNet storm drain net	Easy to install, reusable, distributed free of charge	Reduces urban *Aedes albopictus* breeding
Results	Implementation	Daily spraying during July–August	Pyrethrum 0.5–1%, botanical, fast degrading	Achieved 24-hour suppression; synergistic 15-day residual effect
	Efficacy	CO_2 trap data confirmed significant reductions	≥15 treatments/season create cumulative protective buffer	Effective without environmental contamination
	Compliance	Meets Italian Regional Law 75/95	Collaboration with IPLA SpA, ARPA	Ensures transparency and scientific rigor
	Surveillance Expansion	Starting 2025: 2 additional urban	Comprehensive dataset for trend	Supports early warnings and

Section	Subsection	Content	Key Details / Data	Implications / Actions
		trap stations	analysis	route optimization
Discussion	Key Insights	Predictability, topography, eco-friendly insecticides, GPS-guided operations	Citizen engagement essential	Combines municipal action with household-level interventions
	Lessons Learned	Predictability enables precision; topography enhances efficiency; citizen action multiplies impact		Integrated, scalable model for other regions
Conclusion	Summary	Alessandria provides a replicable, eco-friendly mosquito control model	Combines mobile barrier spraying, entomological surveillance, and citizen-based source control	Effective and environmentally responsible vector management
Declarations	Ethics	Not applicable		
	Data Availability	All data included in article		
	Funding	No specific funding		
	Competing Interests	None declared		
	Author Contributions	E.A. designed, executed, and wrote the study		
	Acknowledgments	Thanks to Research Vice-Chancellor of Shiraz University of Medical Sciences		

Discussion

Conclusion and Strategic Outlook

The city of Alessandria stands today as a model for integrated and ecologically sensitive mosquito control in peri-urban Europe. Confronted with the formidable challenge posed by *Ochlerotatus caspius* a highly migratory and aggressive mosquito species emerging from the rice paddies north of the Po River the municipality has succeeded in designing and deploying a multifaceted, data-driven strategy that exemplifies innovation in public health and environmental management. The operational core of this strategy is the Mobile Anti-Mosquito Barrier, which targets mosquitoes during their short but highly predictable twilight migratory flights. By dividing the 27-kilometer semicircular barrier into color-coded sectors and coordinating slow-moving, high-altitude nebulization using natural pyrethrum, Alessandria has demonstrated that it is possible to intercept and suppress mosquito populations effectively without resorting to broad-spectrum environmental spraying or invasive larvicidal methods. The repeated treatments, timed precisely to coincide with peak mosquito activity, result in a synergistic suppression effect that can last up to 15 days when applied systematically(Becker et al. 2010; Medlock et al. 2015).

Just as critical to the project's success is its reliance on entomological surveillance and microclimatic data collection. The strategic placement of CO_2-baited traps, combined with the use of WBGT sensors and thermal cameras, provides a continuous feedback loop that allows treatments to be refined in real time. This data-centric approach ensures that resources are deployed efficiently, with interventions tailored to match ecological conditions and forecasted infestation peaks. Beyond its operational excellence, the project also sets a benchmark in community-based engagement. The introduction of TombiniNet, a low-cost, high-impact intervention for storm drains, empowers citizens to take direct action within their own properties addressing the estimated 60–80% of urban *Aedes albopictus* breeding that occurs in private domains. By pairing municipal-scale adulticide control with household-level source reduction, Alessandria has embraced a "whole-society" model for vector management(Bowman et al. 2016; Vanlerberghe et al. 2009).

This dual-track approach combining centralized, mobile intervention with decentralized, citizen-led prevention offers a replicable and scalable framework for other cities in Italy and across Southern Europe. As climate change accelerates the geographic expansion of mosquito vectors and the diseases they carry, such as West Nile Virus, Dengue, and Chikungunya, the importance of adaptive and ecologically responsible mosquito control will only grow. Several key lessons emerge from the Alessandria experience, The evening flight patterns of *O. caspius* offer a tactical advantage when leveraged correctly through timing-based interventions (Predictability enables precision). Understanding and exploiting the natural "funnel effect" created by hills and river plains can enhance spatial efficiency (Topography matters). The use of natural pyrethrum, GPS-guided routes, and real-time data collection ensures both environmental and operational resilience (Technology strengthens sustainability). Citizen involvement is not an accessory it is a critical component in achieving long-term suppression (Community action multiplies impact)(DE FELICI et al. 2016; Gingrich et al. 2001).

Looking ahead, further integration of drone-based larvicidal applications in upstream rice paddies, cross-municipal collaboration with neighboring jurisdictions, and continued innovation in low-impact repellents and traps may enhance the strategy's reach and effectiveness. Partnerships with academic institutions

and participation in international consortia (e.g., COST Action CA16227) provide avenues for knowledge sharing and continual methodological refinement. In sum, Alessandria's integrated mosquito control plan serves as both a blueprint and an inspiration illustrating that with scientific rigor, strategic planning, and civic participation, even the most aggressive and mobile mosquito populations can be effectively contained without compromising ecological balance or public trust(Chen et al. 2019; El-Hefnawy et al. 2020).

Declarations

Ethics approval and consent to participate

Not applicable

Clinical trial number

Not applicable

This study did not involve any human participants, clinical interventions, or registered clinical trial procedures.

Data Availability Statement

All data generated or analyzed during this study are included in this published article.

Competing interests

The authors declare no competing interests.

Consent for publication

Not applicable

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Authors' contributions

Ebrahim Abbasi conceived and designed the study, coordinated the manuscript preparation, performed data interpretation, and drafted the manuscript. Asghar Talbalaghi contributed to field operations, entomological surveillance, operational planning, and technical validation of mosquito control interventions in Alessandria. Stefano De Marco participated in field implementation, environmental monitoring, data collection, and operational logistics. Alberto Vedovello contributed to surveillance

activities, field coordination, technical support, and manuscript revision. All authors reviewed, revised, and approved the final version of the manuscript.

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Figures

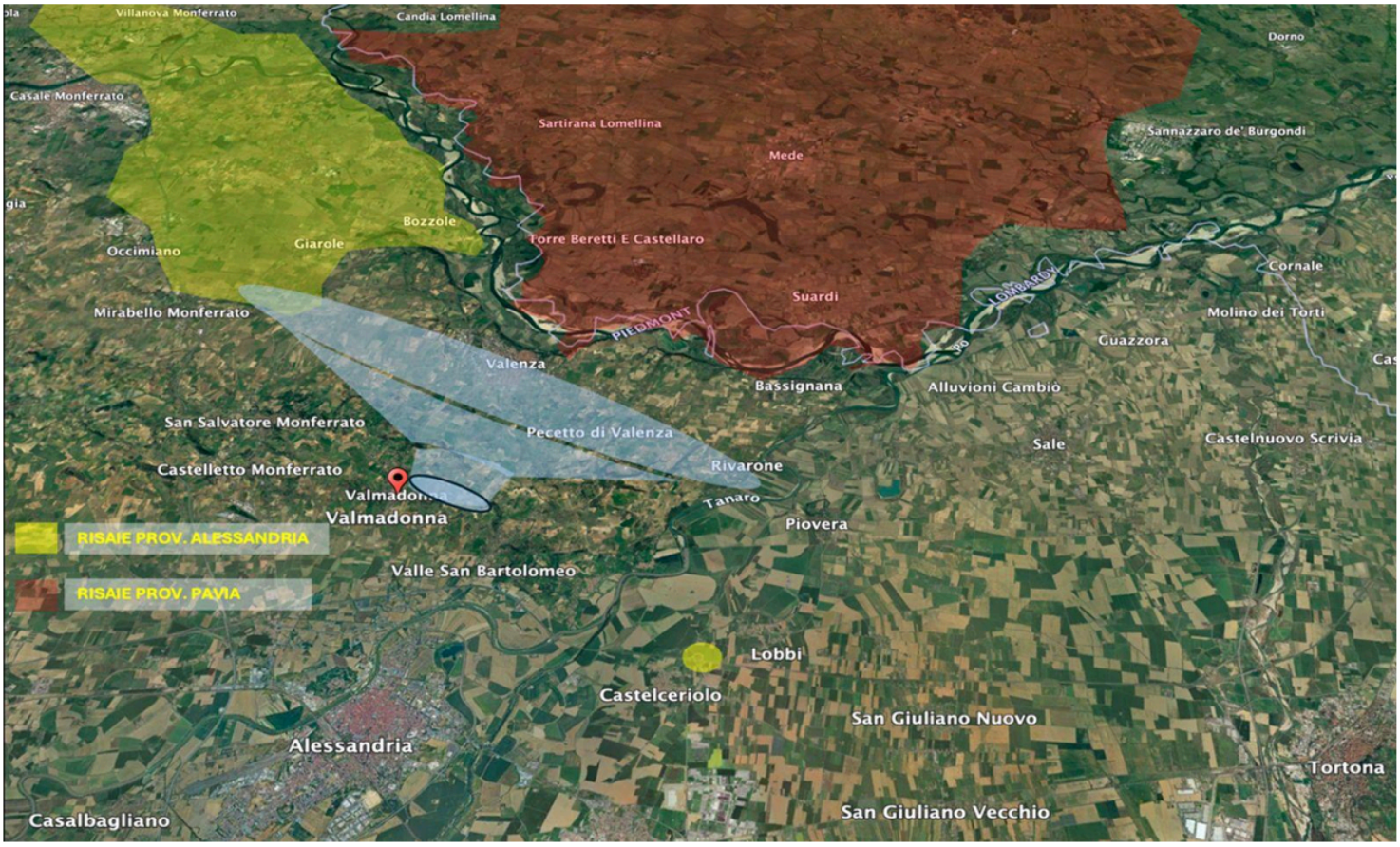


Figure 1

Funnel Effect

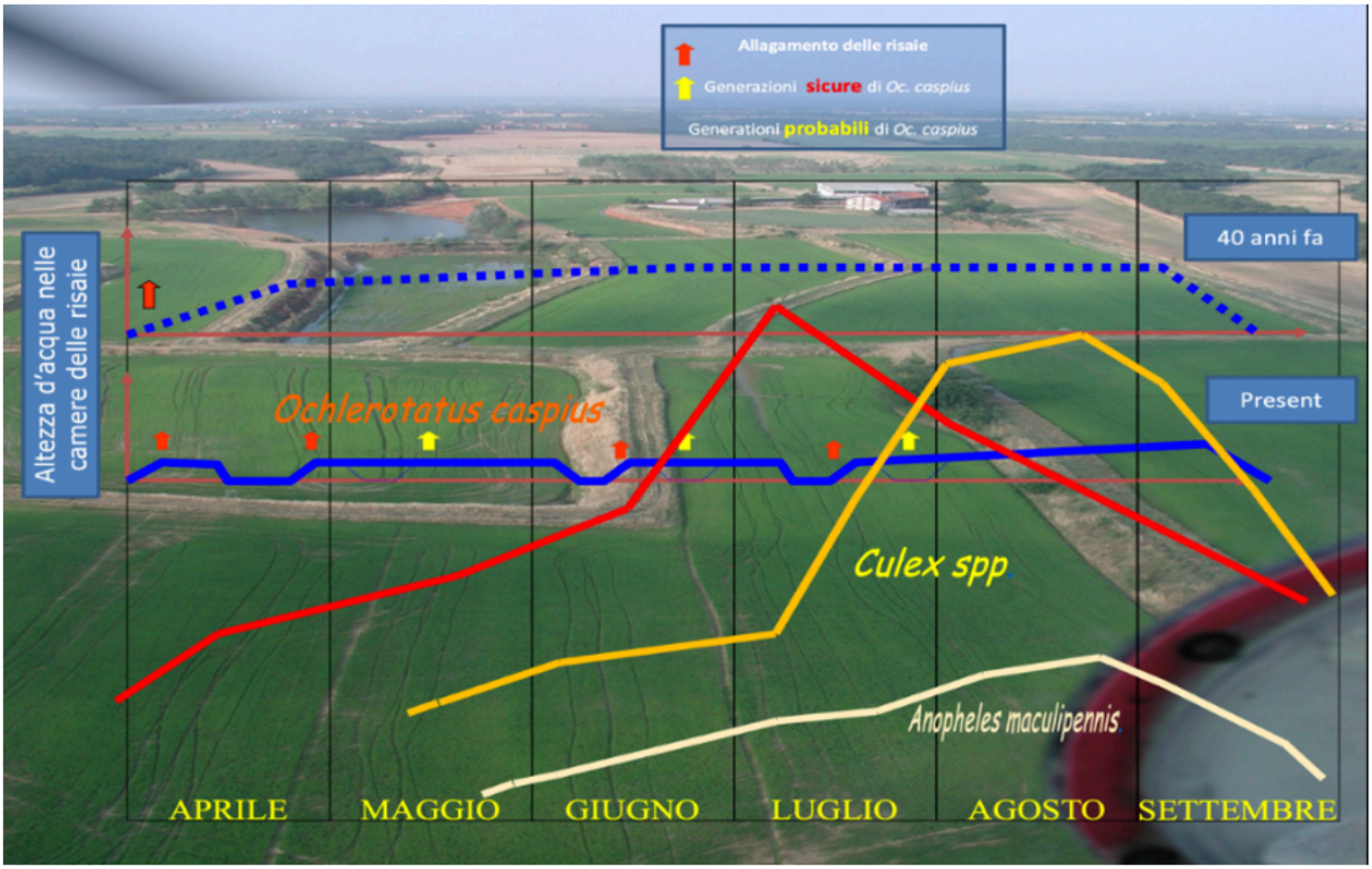


Figure 2

Infestations in the Rice Fields

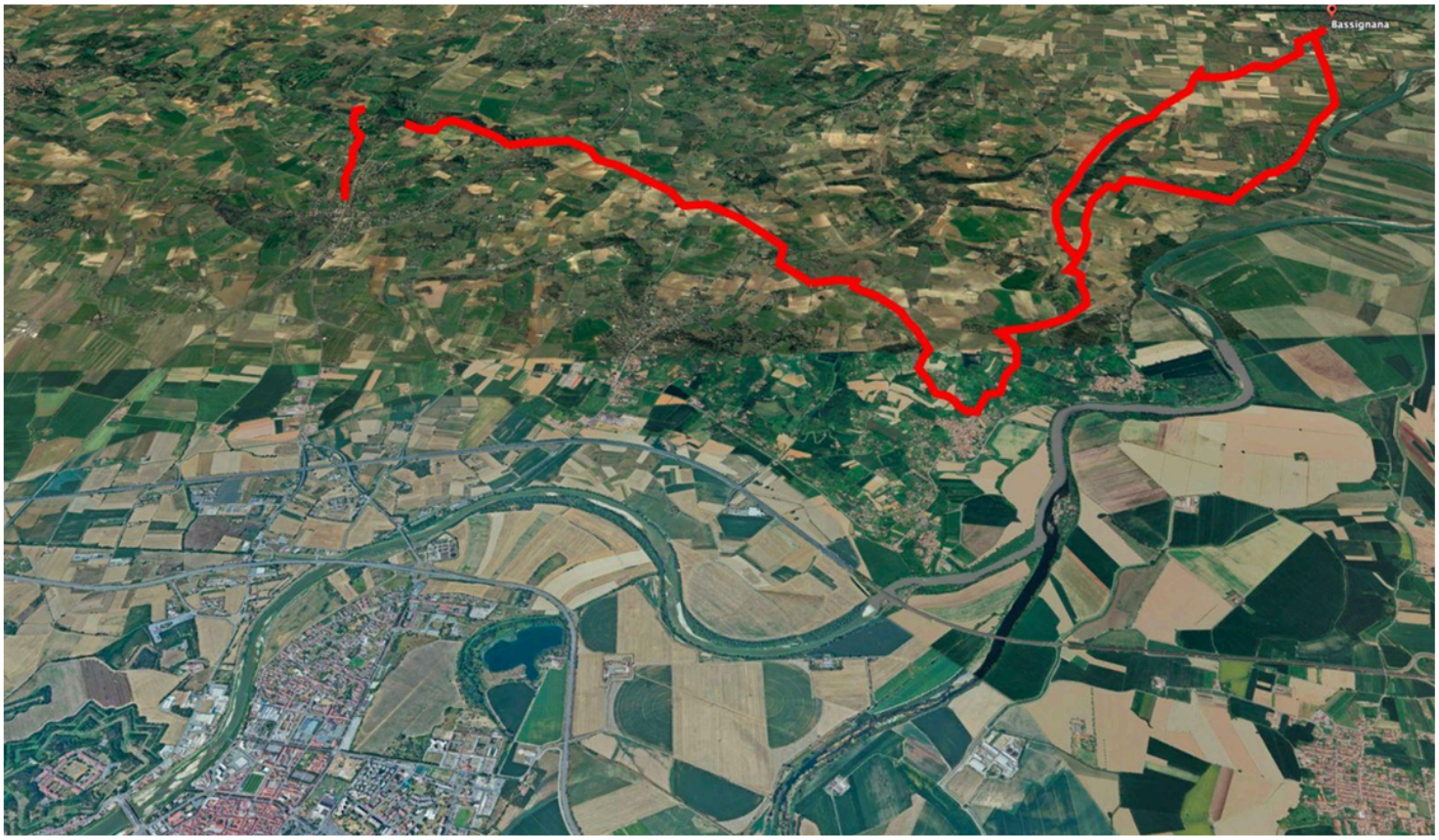


Figure 3

Intervention Route – Path 2 (Hill Route)

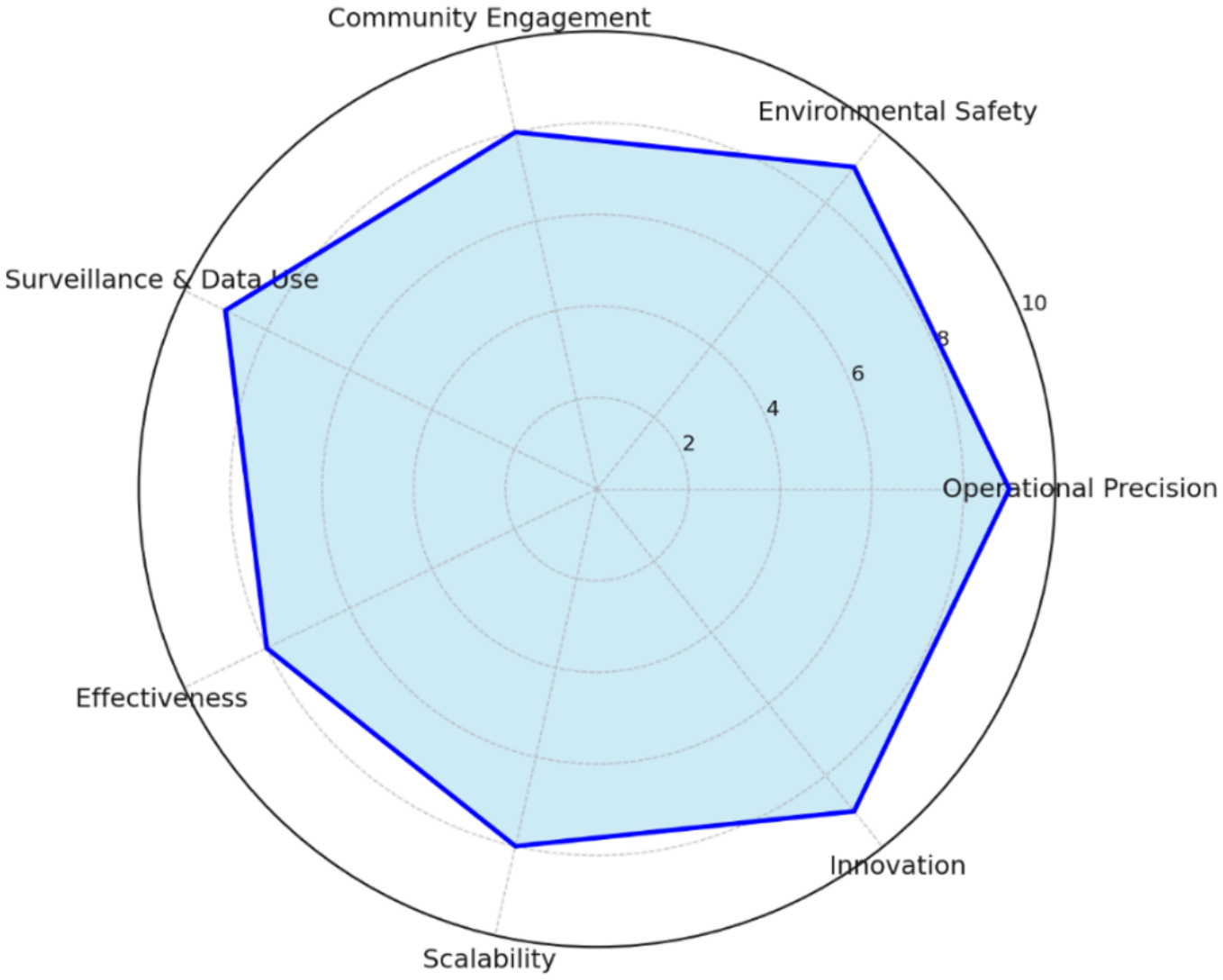


Figure 4

Radar Chart – Integrated Mosquito Management in Alessandria