New tools in mosquito control with special emphasis on the *Wolbachia* strategy

Rubén Bueno-Marí[1,2,3], María Cholvi[2,3,4], Riccardo Moretti[5]

[1]Centre of Excellence in Vector Control for Europe. Rentokil Initial. Paterna. Valencia. Spain. [2]Technical Department. Laboratorios Lokímica. Barcelona. Spain. [3]Area of Parasitology. Department of Pharmacy and Pharmaceutical Technology and Parasitology. Faculty of Pharmacy. Universitat de València. Valencia. Spain. [4]Department of Nursing. Faculty of Medicine and Health Sciences. Catholic University of Valencia. Valencia. Spain. [5]Casaccia Research Center. Department for Sustainability. Italian National Agency for New Technologies, Energy, and Sustainable Economic Development (ENEA). Rome. Italy.

Enf Emerg 2026;25(2):67-70
doi: 10.18176/enfemerg.0016

Summary

The Asian tiger mosquito (*Aedes albopictus*) in Europe has demonstrated an incredible ability to adapt and evade current control strategies, resulting in an increasing number of areas being affected by the presence of this vector. The epidemiological situation in Europe is beginning to shift towards a disturbing situation, exacerbated by various multifactorial variables that affect the transmission of vector-borne diseases. With these extreme phenomena and ever-increasing human mobility, it is necessary to focus on new approaches to vector control that complement traditional methods, as the emergence of insecticide resistance now adds another limiting factor. The use of the *Wolbachia* endosymbiont to create an insect population that is unable to reproduce presents itself as a very promising approach. This natural bacterium, present in the ecosystem, lives inside the cells and causes a reproductive failure that results solely in the sterility of the mosquito without affecting its health. The release of sterile males carrying this bacterium would constitute a minimally invasive, clean and environmentally friendly technique, and has proven effective in other countries where projects have been implemented, such as Australia, Mexico and the United States. The success of these initiatives depends on rigorous monitoring, effective communication with local leaders and authorities, and the development of strong relationships of trust with the local population. This institutional support, combined with community involvement, is key to the success of this scientific innovation.

Keywords:
Asian tiger mosquito (*Aedes albopictus*). *Wolbachia*. Incompatible Insect Technique. Insecticide resistance. Vector control.

Nuevas herramientas en el control de mosquitos con especial énfasis en la estrategia *Wolbachia*

Resumen

El mosquito tigre asiático (*Aedes albopictus*) en Europa ha demostrado una increíble capacidad de adaptación y resiliencia a las estrategias de control actuales, lo que ha provocado un aumento en el número de áreas afectadas por la presencia de este vector. La situación epidemiológica en Europa está comenzando a tornarse preocupante, exacerbada por diversas variables multifactoriales que afectan la transmisión de enfermedades transmitidas por estos vectores. Ante estos fenómenos extremos y la creciente movilidad humana, es necesario centrarse en nuevos enfoques para el control de vectores que complementen los métodos tradicionales, ya que la aparición de resistencia a los insecticidas supone un factor limitante adicional El uso del endosimbionte *Wolbachia* para crear una población de insectos incapaz de reproducirse (Técnica del Insecto Incompatible) se presenta como un enfoque muy prometedor. Esta bacteria natural, presente en el ecosistema, vive dentro de las células y provoca un fallo reproductivo que resulta únicamente en la esterilidad del mosquito sin afectar su salud. La liberación de machos estériles portadores de esta bacteria constituiría una técnica mínimamente invasiva, sostenible y respetuosa con el medio ambiente, y ha demostrado su eficacia en otros países donde se han implementado proyectos, como Australia, México y Estados Unidos. El éxito de estas iniciativas depende de un seguimiento riguroso, una comunicación eficaz con las autoridades locales, y el desarrollo de sólidas relaciones de confianza con la población local. Este apoyo institucional, junto con la participación de la comunidad, es clave para el éxito de esta innovación científica en materia de lucha antivectorial.

Palabras clave:
Mosquito tigre (*Aedes albopictus*). *Wolbachia*. Técnica del Insecto Incompatible. Resistencia a insecticidas. Lucha antivectorial.

Correspondencia: Rubén Bueno-Marí
E-mail: ruben.bueno@rentokil-initial.com

Epidemiological picture of Europe

Despite the efforts of the last thirty years, the spread of new mosquito vector species across European borders seems unstoppable. We already observed *Aedes albopictus* to gradually establish in most of Mediterranean Europe at a rate that outpaced surveillance efforts and *Aedes aegypti* has begun to exhibit the same aggressive expansion patterns.

Concurrently, mosquito-borne diseases are clearly on the upswing. A multifactorial landscape defined by high cross-border mobility, global trade, and warming climates with erratic and unpredictable episodes, has made Europe more vulnerable to pathogen transmission. Frequent, long-lasting heatwaves and heavy flooding damage urban areas, creating new sources for breeding, while overcrowded tourism further facilitates the spread of both vectors and mosquito-borne viruses[1].

What were isolated cases or imported are gradually turning into autochthonous outbreaks. France, Italy, and Spain have consistently reported dengue cases, with 2023 and 2024 reaching record highs. Although West Nile Virus is considered endemic and typically follows predictable seasonal fluctuations, it is now expanding into previously unaffected regions, such as Germany and the Balkans. Furthermore, chikungunya cases saw a significant surge in 2025, with France alone recording over one thousand infected individuals. Preventing this situation from getting further is essential.

The geographic and temporal boundaries of vector-borne diseases in Europe are rapidly shifting. As more countries report established, stable mosquito vector populations, the transmission window continues to expand, with records of mosquito adult activities spanning from March to November in Southern Europe. This underscores the urgent need for adaptive and effective public health strategies[2].

Limits of the traditional control measures and new perspectives

Traditionally, vector control measures have relied on environmental sanitation to ensure that surroundings are unfavourable for the growth of target species. This primarily involves the physical management of breeding sites, which remains the most effective first-line option. Alongside physical measures, chemical methods targeting both larval and adult stages have been standard practice; however, these are increasingly losing their efficacy[2].

The primary cause is the proliferation of knockdown resistance (kdr) mutations, which are genetic alterations in the voltage-gated sodium channels of an insect's nervous system. These mutations reduce the sensitivity of the vector to insecticides such as pyrethroids, essentially allowing the species to survive chemical exposure[3]. To supplement these strategies, alternative approaches are emerging, such as biological methods that employ predatory organisms or pathogens to control populations, and cultural methods that focus on raising public awareness and promoting behavioural change through health education campaigns[2].

While these combined approaches have provided short and medium-term gains, scientific evidence now indicates that a broader perspective is required. Effectiveness must be balanced with economic sustainability for long-term intervention, shifting toward a more integrated model that moves away from isolated techniques and toward a multi-modal strategy tailored to the evolving biology of the species.

Exploitation of *Wolbachia*: incompatible insect technique and population replacement strategies

Wolbachia is an endosymbiotic bacterium found in approximately 65% of all insect species that, thanks to peculiar properties, can be exploited for disease control. It acts as a reproductive parasite that does not harm the host, employing physiological strategies to favour the survival of infected females, ensuring its own transmission to future generations. One of these strategies is cytoplasmic incompatibility (CI)[c].

CI occurs when a male carrying a specific *Wolbachia* strain mates with a female harbouring a different strain (or none at all). This incompatibility results in embryonic death due to failure in chromosome pairing. Although the specific molecular mechanisms behind this phenomenon are still being researched, its practical applications are significant. In species like *Aedes albopictus*, which naturally carry *Wolbachia*, the release of males infected with a different strain of the bacterium can lead to CI-based population suppression (Incompatible Insect Technique = IIT)[4,5].

Certain *Wolbachia* strains are also capable of reducing the capacity by viruses to infect insects and, based on this feature and on the mechanism of CI, a different *Wolbachia*-based control strategy is under open field testing in various countries in the Tropics (where dengue and other arboviruses are endemic). This strategy, Population Replacement, does not aim at vector suppression but at making vectors less capable at transmitting viruses. These control programs regard Aedes aegypti and involve

releasing *Ae. aegypti* males and females infected with a *Wolbachia* strain that induces both CI and reduction of the vector competence to allow released females to invade the wild population until full replacement. In fact, being *Wolbachia* absent in *Ae. aegypti*, released infected females can be fertilized by both wild and infected males outcompeting the wild females that instead are sterilized by the infected males. In this scenario, *Wolbachia* slows the replication of certain viruses within the mosquito, significantly reducing their vector competence[4].

Wolbachia-based control is worldwide considered safe and cost-effective because it relies on a ubiquitous and non-pathogenetic organism and open field deployment does not require any pre-release treatment. Incompatible males show fully preserved fitness compared to wild males and methods for a perfect sex sorting are already available and consent only-male releases in the case of IIT programs[6-9] (Figure 1).

First experiences and perspectives of implementation

Following early 2012 trials in tropical climates, IIT implementations expanded globally to focus predominantly on *Ae. aegypti* in areas including California (USA), Queensland (AU), Singapore, and the Caribbean, with *Ae. albopictus* targeted to a lesser extent. In Europe, the first IIT trials were conducted in Rome (2018–2019), where 1:1 releases (incompatible:wild males) led to an approximate 40% reduction in egg hatching rates[4,8,9].

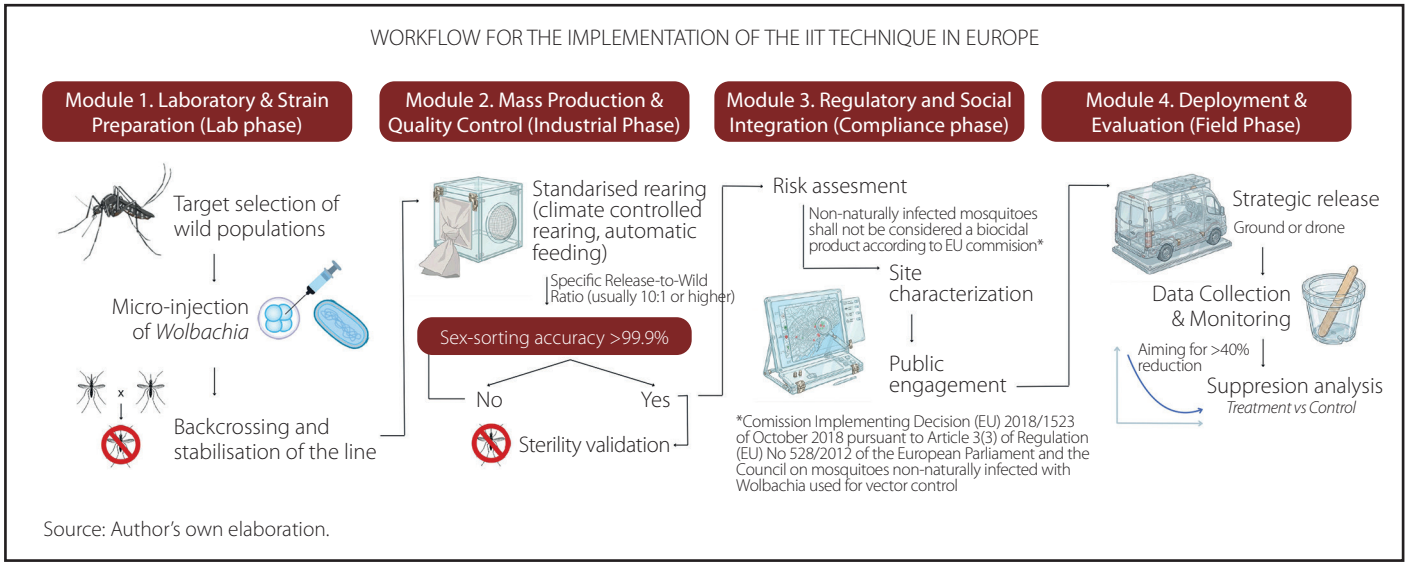
Overall, evidence from open field trials suggest that IIT is a highly promising and effective biological control strategy for managing disease vectors within the European context.

Integrating all available monitoring and control measures with the community

The success of *Wolbachia*-based interventions depends on rigorous monitoring to accurately evaluate the impact of IIT or Population Replacement releases, as well as on sustained community engagement. Successful programs consistently build strong partnerships with local communities and relevant authorities, ensuring that operational deployment is complemented by collective efforts to eliminate breeding sites, avoid interference with sterile mosquitoes, and promote a clear understanding of the intervention's purpose. As an example, during the development of local Population Replacement initiatives led by the World Mosquito Program (https://www.worldmosquitoprogram.org/), local stakeholders and community leaders are systematically involved. Furthermore, safeguarding monitoring systems is critical, requiring measures to prevent the displacement, tampering, or removal of traps and associated equipment[10,11].

The implementation of *Wolbachia*-based control strategies is demonstrating promising results, particularly in localized pilot programs targeting *Aedes* species. However, their long-term effectiveness depends on sustained funding, coordinated cross-

Figure 1. Integrated workflow for the implementation of the Incompatible Insect Technique (IIT) in European urban environments. The process transitions from (1) laboratory strain stabilization and (2) industrial mass-rearing with rigorous sex-sorting, through (3) regulatory compliance under EU biocidal frameworks, concluding in (4) field release and suppression monitoring.



Source: Author's own elaboration.

border strategies, and continued public engagement. As these approaches are scaled up, integrating scientific innovation with strong institutional and community support will be essential to ensure durable and widespread impact[4].

Bibliography

1. Branda F, Cella E, Scarpa F, Slavov SN, Bevivino A, Moretti R, *et al*. Wolbachia-Based Approaches to Controlling Mosquito-Borne Viral Threats: Innovations, AI Integration, and Future Directions in the Context of Climate Change. *Viruses*. 2024;16(12):1868. doi: 10.3390/v16121868.
2. Cholvi M, Moretti R, Osório HC, L'Ambert G, Seixas G, Kavran M, *et al*. Present and Future of Mosquito-Borne Disease Control in Europe with a Specific Focus on the Mediterranean. *Insects*. 2026;17(3):254. doi: 10.3390/insects17030254.
3. Pichler V, Valadas V, Akiner MM, Balatsos G, Barceló C, Borg ML, *et al*. Tracking pyrethroid resistance in arbovirus mosquito vectors: mutations I1532T and F1534C in Aedes albopictus across Europe. *Parasit Vectors.* 2025;18(1):506. doi: 10.1186/s13071-025-07130-1.
4. Moretti R, Lim JT, Ferreira AGA, Ponti L, Giovanetti M, Yi CJ, *et al*. Exploiting Wolbachia as a Tool for Mosquito-Borne Disease Control: Pursuing Efficacy, Safety, and Sustainability. *Pathogens*. 2025;14(3):285. doi: 10.3390/pathogens14030285.
5. Calvitti M, Moretti R, Skidmore AR, Dobson SL. Wolbachia strain wPip yields a pattern of cytoplasmic incompatibility enhancing a Wolbachia-based suppression strategy against the disease vector Aedes albopictus. *Parasit Vectors*. 2012;5:254.
6. Cholvi M, Trelis M, Bueno-Marí R, Khoubbane M, Gil R, Marcilla A, *et al*. Wolbachia Infection through Hybridization to Enhance an Incompatible Insect Technique-Based Suppression of Aedes albopictus in Eastern Spain. *Insects*. 2024;15:206. doi: 10.3390/insects15030206.
7. Lampazzi E, Virgillito C, Caputo B, Lombardi G, Santarelli G, Moretti R, *et al*. Spatial Dynamics and Sterilization Range of Incompatible Aedes albopictus Males: Advancing Toward an Optimized IIT Approach. *Trop Med Infect Dis.* 2026;11(2):45. doi: 10.3390/tropicalmed11020045.
8. Caputo B, Moretti R, Manica M, Serini P, Lampazzi E, Bonanni M, *et al*. A bacterium against the tiger: preliminary evidence of fertility reduction after release of Aedes albopictus males with manipulated Wolbachia infection in an Italian urban area. *Pest Manag Sci.* 2020;76(4):1324-32. doi: 10.1002/ps.5643.
9. Caputo B, Moretti R, Virgillito C, Manica M, Lampazzi E, Lombardi G, *et al*. A bacterium against the tiger: further evidence of the potential of non-inundative releases of males with manipulated Wolbachia infection in reducing fertility of Aedes albopictus field populations in Italy. *Pest Manag Sci.* 2023;79:3167-3176. doi: 10.1002/ps.7495.
10. Velez ID, Tanamas SK, Arbelaez MP, Kutcher SC, Duque SL, Uribe A, *et al*. Reduced dengue incidence following city-wide wMel Wolbachia mosquito releases throughout three Colombian cities: Interrupted time series analysis and a prospective case-control study. *PLOS Negl Trop Dis.* 2023;17(11):e0011713. doi: 10.1371/journal.pntd.0011713.
11. Anders KL, Ribeiro GS, Lopes RDS, Amadeu P, da Costa TR, Riback TIS, *et al*. Long-Term Durability and Public Health Impact of City-Wide wMel Wolbachia Mosquito Releases in Niterói, Brazil, During a Dengue Epidemic Surge. *Trop Med Infect Dis*. 2025;10(9):237. doi: 10.3390/tropicalmed10090237.