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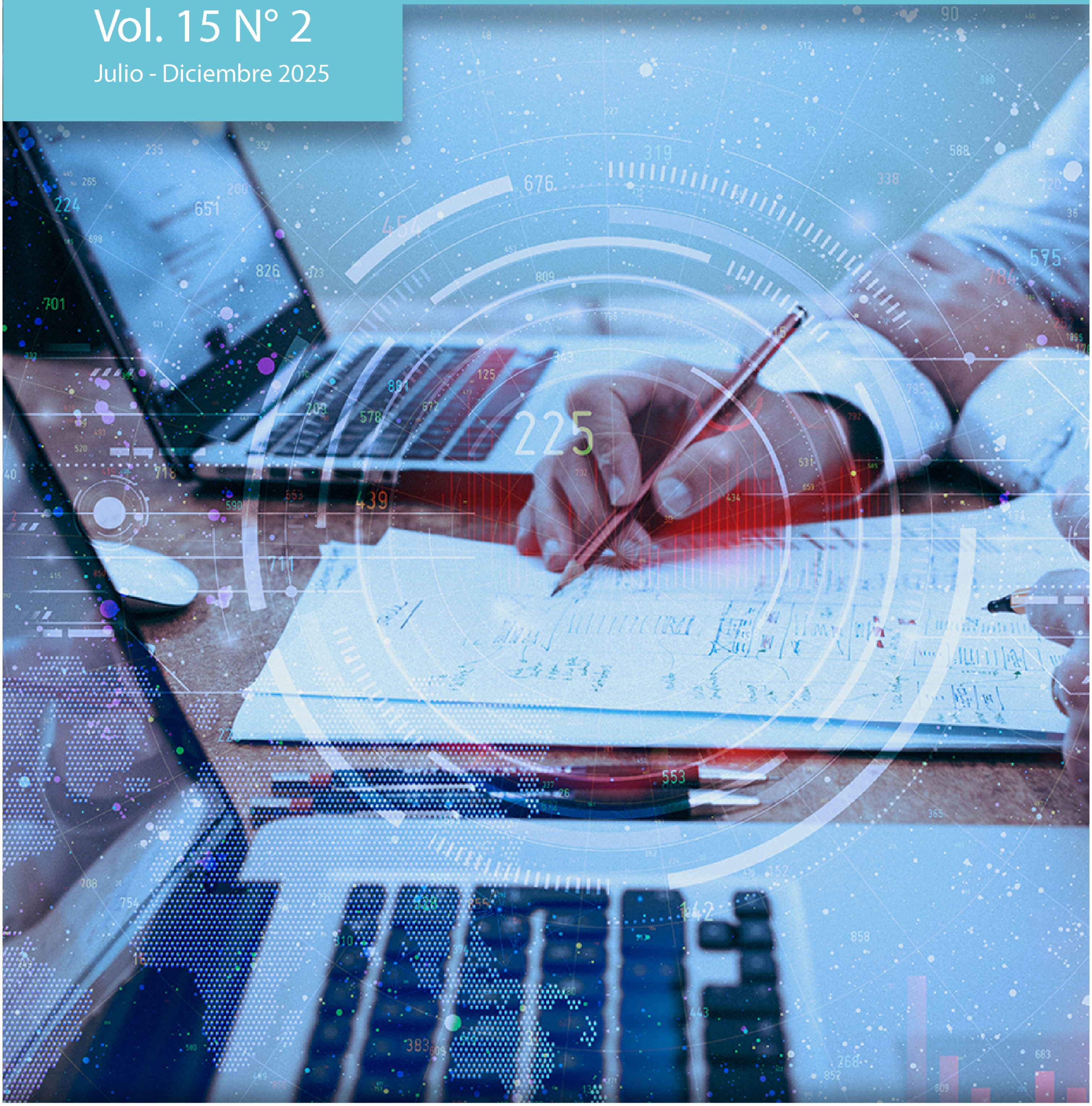

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BIOMEDICAL, ECOSOCIAL, AND EDUCATIONAL APPROACHES TO BIOLOGICAL CONTROL OF MOSQUITO LARVAL HABITATS IN VULNERABLE COMMUNITIES: A COMPREHENSIVE MODEL FOR PREVENTION AND COMMUNITY HEALTH

Enfoques Biomédico - Ecosocial y Educativo para el Control Biológico de Hábitats Larvarios de Mosquitos en Comunidades Vulnerables: Un Modelo Integral de Prevención y Salud Comunitaria

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ABSTRACT

This research explores the biological control of mosquitoes through a multidisciplinary approach, combining biomedical, eco-social, and educational perspectives, with a focus on vulnerable communities. The primary objective is to examine how biological strategies, including the utilization of natural predators and ecological methods, can curb the proliferation of mosquitoes and the diseases they transmit, while fostering community education for the effective management of larval habitats. The methodology employed is a documentary review, which compiles previous studies on biological control in various regions, evaluating its effectiveness and applicability in areas with limited resources. The results show that biological methods, such as the use of predatory fish and copepods, are more sustainable and less costly than insecticides, with a lower environmental impact. Additionally, the importance of community education and participation in managing mosquito breeding sites is emphasized. The conclusions highlight the necessity of a comprehensive approach that integrates biological control, public policies, and educational strategies to address public health challenges in vulnerable communities. This ecological and participatory approach is key to the sustainability and effectiveness of interventions, ensuring lasting and accessible control.

Keywords: Public health, Vector mosquitoes, Medical entomology, Biomedicine, Biological control

RESUMEN

Esta investigación analiza el control biológico de mosquitos desde un enfoque biomedico-ecosocial y educativo, centrado en comunidades vulnerables. El objetivo es explorar cómo los métodos biológicos, como el uso de depredadores naturales, pueden reducir la proliferación de mosquitos y las enfermedades que transmiten, mientras se promueve la educación comunitaria en el manejo de hábitats larvarios. La metodología utilizada es una revisión documental, evaluando estudios previos sobre control biológico en zonas con recursos limitados. Los resultados indican que el control biológico es una alternativa sostenible y económica frente al uso de insecticidas, con menos impacto ambiental. Sin embargo, los hábitos de higiene y el acceso limitado a servicios básicos dificultan el control efectivo de los vectores. Las conclusiones subrayan la necesidad de integrar estrategias de control biológico con educación y participación comunitaria para mejorar la salud pública y lograr soluciones duraderas en comunidades vulnerables.

Palabras clave: Salud pública, Mosquitos vectores, Entomología médica, Biomedicina, Control biológico.

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INTRODUCTION

Vector-borne diseases pose a serious challenge to public health, as they mainly affect the most vulnerable and marginalized communities. These infectious diseases, transmitted by living organisms such as mosquitoes, ticks, fleas, and sandflies, depend on the interaction between the vector and the people or animals that act as hosts. When these blood-feeding arthropods feed on the blood of an infected individual, they acquire pathogenic microorganisms (which can be viruses, bacteria, or parasites) and spread them to other people, thus perpetuating the cycle of transmission. The social impact of these diseases is profound, as they not only cause suffering and mortality but also exacerbate inequality and hinder the development of affected communities by limiting their access to education, work, and a healthy life (Llivipuma Sanmartin, 2025).

Growing concern about the adverse effects of indiscriminate pesticide use in vector control has led to the search for more sustainable and environmentally friendly alternatives. The prolonged use of these chemical agents has encouraged the emergence of resistance in mosquito populations, while also causing environmental pollution, the destruction of beneficial fauna such as natural predators, and the disruption of ecological balances. In addition, the presence of toxic residues in food products and the increased costs of control programs have created a need to explore more environmentally friendly and effective solutions (Padilla, Pardo & Molina, 2017).

In this context, biological vector control is emerging as a promising strategy. This alternative is based on the use of biological agents, such as mosquito parasitic nematodes and larvivorous fish, to reduce disease vector populations. The benefits of biological methods include their specificity in targeting specific organisms, their relatively low research and development costs, and their minimal environmental impact. In countries such as the United States, Brazil, Mexico, and Cuba, the implementation of bioplants for producing these biological agents has proven effective in vector control, contributing to the reduction of mosquito-borne diseases, including dengue, Zika, and chikungunya (Gómez et al., 2020).

At the social level, this problem disproportionately affects vulnerable communities, which face a high risk of exposure to mosquito-borne diseases due to poor infrastructure conditions and limited resources for implementing preventive measures. In this sense, integrating biomedical, eco-social, and educational approaches can be key to promoting sustainable and accessible solutions, combining biological control with community education on preventive practices. This research examines how these approaches can contribute to biological control and the enhancement of larval habitats in vulnerable communities, thereby strengthening the capacity of populations to address public health challenges (Bisset, 2002).

The overall objective of this research is to analyze and propose a biomedical-ecosocial and educational approach to the biological control of mosquito larval habitats in vulnerable communities, promoting sustainable and low-impact alternatives in the fight against vector-borne diseases, thereby improving public health conditions and strengthening prevention capacity in these populations.

METHODOLOGY

The methodology used in this study is documentary in nature, specifically a documentary review, which is used to collect, analyze, and synthesize relevant and up-to-date information on biological vector control, the impact of pesticides, and eco-social and educational interventions in vulnerable communities. This approach provides a comprehensive overview of scientific and practical advances in the field of eco-social biomedicine applied to mosquito control and disease prevention (Hernández et al., 2014; Fernández & Herrera, 2017).

The literature review draws on primary and secondary sources, including scientific articles, technical reports, case studies, theses, and institutional documents, spanning diverse geographical and sociocultural contexts. In particular, previous studies on the use of biological agents in mosquito control, the impact of pesticides on the environment and public health, and educational interventions in vulnerable communities will be selected. The analysis will focus on identifying best practices, the limitations of current approaches, and opportunities for integrating biological methods with educational and social strategies (Palavecino, 2020).

Application of the Documentary Methodology in This Research

The methodology of this research is centered on identifying prior experiences in the biological control of mosquitoes within vulnerable communities, particularly in Latin America and other regions impacted by vector-borne diseases such as dengue, Zika, and chikungunya. The study analyzed the environmental and social impacts of pesticide use, with particular emphasis on applications in high-vulnerability areas, and assessed the advantages of biological alternatives in terms of sustainability and reduced risk. Furthermore, the effectiveness of educational programs aimed at promoting the integration of preventive measures for mosquito control was examined, with consideration given to the active involvement of communities in the identification and management of larval habitats.

In addition, biomedical–ecosocial approaches were systematized in order to propose a model that combines biological control strategies with community-based education, thereby encouraging the proactive participation of vulnerable populations in the prevention and control of disease. The documentary review was conducted through an exhaustive search of academic databases, including PubMed, Scopus, Google Scholar, ResearchGate, and other relevant sources. Subsequently, a critical appraisal of the retrieved information will be undertaken, selecting those studies that contribute robust and contextually relevant evidence to support the objectives of the research (Rodríguez, 2002).

RESULTS AND DISCUSSION

Implications of arthropods for public health: A biomedical-ecosocial and educational approach to the order Diptera in vulnerable communities

The phylum Arthropoda is home to the greatest diversity of species in the animal kingdom, notable for its ability to adapt to a wide variety of habitats and its proximity to human activities. Throughout history, arthropods have been both a blessing and a threat to human well-being. In fact, many of these organisms, particularly those belonging to the Diptera order, such as mosquitoes and flies, have been responsible for the spread of various infectious diseases, posing a significant challenge to public health, especially in vulnerable communities (Pascal, 2021).

From a health and social perspective, the damage caused by these arthropods can be classified into two categories: direct and indirect. Direct damage occurs when pests feed on the fluids or tissues of plants or animals, which can affect both human health and agricultural production. However, the most serious impact occurs when these vectors are associated with the transmission of pathogens or parasites, triggering epidemics of diseases such as dengue, Zika, chikungunya, and malaria, among others. Epidemics derived from these vectors primarily affect the most vulnerable communities, which often have limited access to health services, adequate infrastructure, and preventive education (Bello, 2021).

In terms of transmission, arthropods can act mechanically or biologically. Mechanical transmission does not require a development cycle of the pathogen within the vector, while biological transmission implies that the pathogen must undergo a process of multiplication and development within the vector before it can infect humans. The latter type of transmission is particularly relevant in the case of mosquitoes, such as Aedes aegypti, which not only carry pathogens but also multiply them, exacerbating the risk of infection (López & Fernández, 2017).

Within the order Diptera, mosquitoes and flies are the best-known species, characterized by having a single pair of wings. This group includes species whose transmission mechanisms are crucial in the spread of infectious diseases. At the social level, this reality highlights the urgent need to implement comprehensive control strategies that not only address vector elimination but also promote community education in prevention and the active participation of affected populations. In addition, collaboration with public health systems is essential, as they must facilitate access to treatments and ecological solutions to mitigate the impact of these vectors on the most disadvantaged communities (Palavecino, 2024).

In this context, integrating biomedical, eco-social, and educational approaches in the management of biological mosquito control is a viable strategy for mitigating the negative implications of these arthropods on public health, particularly in areas with high social and environmental vulnerability. The promotion of ecological and sustainable methods, such as the use of biological agents, in combination with community awareness and empowerment, can play a crucial role in mitigating the risks associated with vector-borne diseases (Llivipuma Sanmartin, 2025).

This framework provides a comprehensive view of the implications of arthropods, specifically those of the order Diptera (mosquitoes and flies), on public health from a biomedical, ecological, social, and educational perspective. The biomedical approach highlights the direct impact of these vectors on the transmission of diseases such as dengue, Zika, and malaria, which mainly affect vulnerable populations. Mosquitoes, in particular, are key vectors in the spread of arboviruses and protozoa, and their ability to multiply pathogens within their bodies exacerbates the risks of contagion.

From an eco-social perspective, the interaction between arthropods and human communities illustrates how social, economic, and environmental factors influence the proliferation of these vectors. The lack of adequate infrastructure, combined with poor education on preventive measures and unfavorable living conditions in vulnerable areas, facilitates the spread of mosquito-borne diseases. In this sense, eco-social approaches aim to integrate environmental health with control strategies, promoting the use of sustainable biological methods to reduce disease incidence without harming the environment.

The educational component of this approach is crucial to improving communities' ability to prevent and control the proliferation of mosquitoes. Community awareness and education are essential tools for empowering people, especially in vulnerable areas, enabling them to identify and manage larval habitats and adopt prevention practices such as the use of repellents, the elimination of mosquito breeding sites, and the promotion of environmental hygiene. This comprehensive approach seeks not only to control vectors effectively but also to ensure that communities understand the importance of these actions for improving public health and collective well-being.

Mosquito Larval Habitats: A Biomedical, Eco-Social, and Educational Approach to Management in Vulnerable Communities

The concept of habitat refers to a set of physical, geographical, and environmental factors that influence the development and survival of a population or species within a given ecosystem. In the case of mosquitoes, larval habitats are essential aquatic environments that support the life cycle of these vectors, particularly during their larval and pupal stages. These habitats are characterized by areas where stagnant or temporary water creates ideal conditions for the reproduction and development of larvae. It should be noted that these habitats are not only a key ecological component but also have direct implications for public health, as they are the main places where mosquitoes can transmit diseases such as dengue, Zika, and chikungunya, particularly in vulnerable communities (Rodríguez, 2002; Pascal, 2023).

Mosquito larvae and pupae require water for their development, but they must reach the surface to obtain oxygen. Mosquitoes lay their eggs in damp places or on surfaces near the waterline. These eggs remain dry until they are flooded by rain, at which point they hatch and the larvae begin their life cycle. Larval habitats include puddles and temporary ponds formed by rain, floodplains near streams and riverbanks, irrigated fields and meadows, containers that accumulate water after rainfall, and holes in trees that collect rainwater. This type of habitat is particularly linked to human practices and social conditions that favor the proliferation of vectors, such as inadequate access to drinking water services and the accumulation of discarded objects that serve as water reservoirs (Zavala et al., 2024).

The *Aedes aegypti* mosquito, known for its synanthropic behavior, is a clear example of how domestic larval habitats are favored by human interaction. These mosquitoes colonize a variety of habitats that are often generated by deficiencies in water services, such as inadequate water storage for human consumption, the presence of ornamental plants, and the accumulation of useless objects in yards and gardens, which can store rainwater. In this sense, social conditions and inadequate infrastructure play a crucial role in creating habitats conducive to the proliferation of these vectors (Bisset, 2002).

From a biomedical-ecosocial perspective, the management of larval habitats must be considered not only from an ecological approach but also from a social perspective. Vulnerable communities, which often lack access to safe drinking water and adequate sanitation, are at greater risk of mosquito-borne diseases. Community education and the promotion of sustainable environmental management practices, such as eliminating breeding sites and covering water containers, are fundamental tools in prevention. Additionally, the use of monitoring tools, such as the pupal index (PID) calculation, based on the type of container or reservoir where larval stages are found, can be crucial in identifying and controlling risk areas within the community (Pascal, 2025).

This biomedical-ecosocial approach emphasizes the importance of integrating scientific knowledge with educational and community strategies for the effective management of larval habitats, thereby reducing the spread of disease and enhancing public health in vulnerable areas (Hernández, 2018).

Within this argumentative framework, it is highlighted that mosquito breeding habitats, far from being merely an ecological problem, pose a significant challenge to public health, especially in vulnerable communities. From a biomedical perspective, the aquatic habitats where mosquitoes lay their eggs and develop their larvae are critical hotspots for disease transmission. *Aedes aegypti*, which colonizes these habitats close to human dwellings, is responsible for the spread of dangerous arboviruses such as dengue, Zika, and chikungunya, diseases that mainly affect communities with limited resources. The presence of standing water, both in natural areas and in objects accumulated by humans, creates the ideal environment for the development of these species, putting the health of the population at risk.

From an eco-social perspective, social, economic, and environmental factors play a crucial role in the creation of these habitats. Lack of access to basic services such as drinking water and adequate sanitation, coupled with the accumulation of useless objects in domestic and community spaces, contributes to the proliferation of vectors. This underscores the need for an integrated intervention that not only considers mosquito control from a biological standpoint but also addresses the social conditions that favor their proliferation. Vulnerable communities, which often lack adequate infrastructure, are particularly exposed to these threats, amplifying inequality in terms of health and well-being.

The educational component of this approach is fundamental. Awareness-raising and education in environmental management are essential tools for empowering communities to identify and eliminate mosquito breeding sites. Implementing strategies that include covering water containers, using environmentally friendly biological control methods, and promoting the cleanliness of public and private spaces are fundamental practices that must be adopted jointly. Empowering communities to actively manage larval habitats not only enhances the effectiveness of interventions but also fosters a sustainable and proactive approach to mosquito-borne diseases.

Biological control of mosquitoes: A biomedical, eco-social, and educational approach to prevention and management in vulnerable communities

Biological mosquito control is based on an ecological interaction known as the predator-prey relationship, in which an antagonistic relationship is established between two organisms: one acts as a predator and the other as prey. This interaction is a natural mechanism that helps maintain ecological balance. Predators control prey populations by consuming them, and in turn, prey regulate their size and use of available resources, such as food and space. In a healthy ecosystem, both populations balance each other, promoting environmental stability (Palavecino, 2024; PAHO, 2020).

From a biomedical-ecosocial approach, biological control of mosquito vectors involves the use of natural enemies of these species, such as fish, aquatic insects, and bacteria, to reduce the mosquito population and minimize the risks associated with vector-borne diseases, including dengue, Zika, and chikungunya. Mosquitoes, particularly *Aedes aegypti*, breed in small pools of stagnant water, such as discarded tires, cans, and bottles, highlighting the relationship between hygiene conditions and the proliferation of these vectors in vulnerable communities (Imperato, 2016; Bello, 2021).

Despite educational efforts in communities to promote the elimination of breeding sites, poor hygiene habits, such as littering in yards, streets, and vacant lots, hinder effective control of these breeding grounds. This social reality highlights the need for a comprehensive approach that not only relies on physical and chemical control but also addresses the social and cultural factors that perpetuate the proliferation of mosquitoes. Community education plays a crucial role in this context, encouraging the active participation of the population in managing their environment and implementing prevention practices (Bueno et al., 2009).

Chemical control, although effective in the short term through insecticide spraying, has significant limitations. Despite its rapid action in eliminating adult mosquitoes, it does not affect immature stages, requiring repeated applications and potentially favoring the emergence of resistant mosquito strains. These interventions, while useful, are costly and pose additional environmental risks. In this regard, biological control with natural enemies, such as small predatory fish, bacteria like *Bacillus thuringiensis*, and copepods like *Mesocyclops longisetus*, presents itself as a more sustainable and ecological alternative. These methods are effective in several studies, particularly in countries in the Americas and Asia, by reducing mosquito populations without the side effects associated with chemical use (Diéguez et al., 2019; Zavala et al., 2024).

Copepods, small planktonic crustaceans, have shown significant potential in preying on Aedes aegypti larvae. Studies conducted in Central America, such as in Costa Rica, have found that *Mesocyclops thermocyclopoides* is one of the most abundant and effective genera in reducing larvae. This approach not only promotes public health but also highlights the importance of local biodiversity as a means of control. Similarly, the use of predatory fish such as *Poecilia reticulata* (guppy) has been a successful strategy in several aquatic ecosystems. This species, with its high reproductive capacity and adaptability to polluted conditions, has proven effective in reducing mosquito larvae, underscoring the importance of considering biological solutions adapted to local environments (Pascal, 2017; Diéguez et al, 2019).

Under these premises, a comprehensive and multidimensional approach to mosquito control is reflected, which goes beyond the application of biological methods to include the social and educational dimensions essential for the sustainability and effectiveness of these interventions. From a biomedical perspective, biological control is presented as a promising solution to the limitations of traditional chemical methods, such as insecticide spraying. Although these methods can quickly eliminate adult mosquitoes, their impact is limited in the immature stages, and their repeated use contributes to vector resistance and environmental pollution. In contrast, biological control through natural predators, such as fish and copepods, offers a more sustainable solution, with fewer adverse effects and without the risk of generating resistant strains.

From an eco-social perspective, the analysis highlights how social and environmental factors directly influence the proliferation of mosquitoes. In vulnerable communities, where access to basic services such as drinking water and sanitation is limited, managing larval habitats and eliminating breeding sites becomes a constant challenge. Despite educational efforts, poor hygiene habits and the accumulation of waste in yards and streets continue to be important factors contributing to the increase in vectors. This context underscores the importance of addressing mosquito control from a social perspective, recognizing that community education and behavioral change are crucial for the long-term effectiveness of control strategies.

Finally, the educational component of this approach is key. The implementation of biological control techniques, such as the use of predatory fish such as *Poecilia reticulata* and other aquatic organisms, is complemented by an effort to raise awareness among communities about the importance of eliminating breeding sites and adopting hygienic practices in their environments. Through educational programs, communities can learn to manage their resources more efficiently and sustainably reduce exposure to mosquitoes. This approach also promotes the active participation of the population in managing their environment, which can significantly improve the effectiveness of interventions and foster a sense of shared responsibility in disease prevention.

Towards an Integral Model: Synergy between Biomedical, Ecosocial, and Educational Approaches for Prevention and Community Health

The proposed conceptual model (Figure 1) emerges as a structural and systemic response to the complex problem of mosquito vectors in vulnerable communities. Far from being a mere sum of isolated initiatives, this model is conceptualized as a synergistic framework in which three fundamental approaches (Biomedical, Ecosocial, and Educational) interact dynamically and continuously to achieve a sustainable impact on disease prevention and the promotion of community health. The logic and flow of this integral model are broken down below.

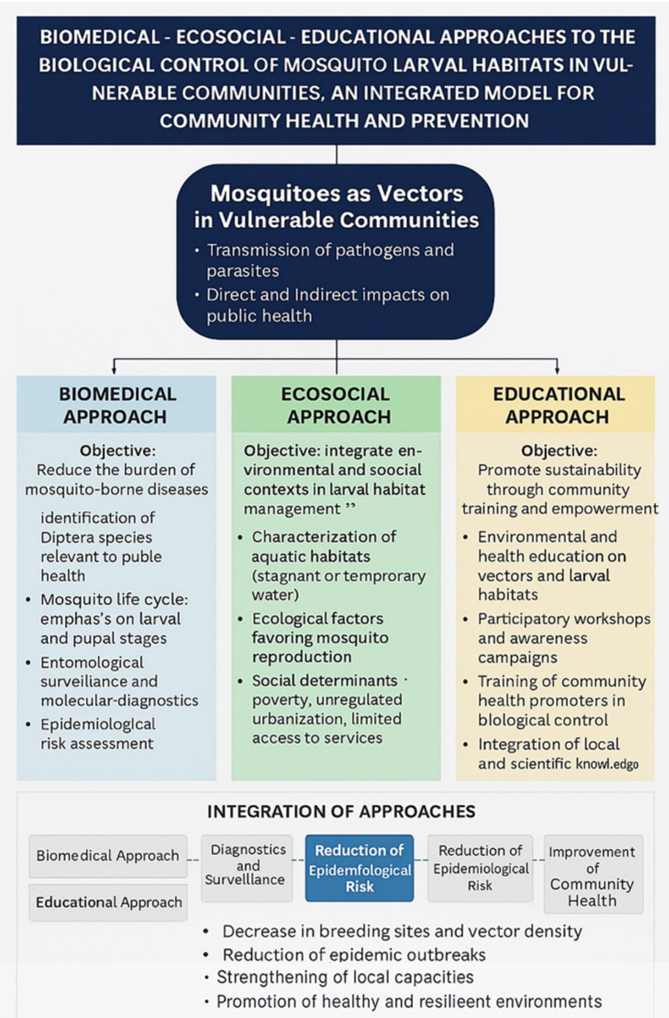

Figure 1. This conceptual framework illustrates the articulation of biomedical, ecosocial, and educational approaches for the prevention and management of mosquito-borne diseases. The model emphasizes the intersection of entomological surveillance, ecological habitat management, and community empowerment as key pillars for sustainable vector control. Each approach contributes distinct but complementary strategies: biomedical interventions focus on species identification and epidemiological risk assessment; ecosocial strategies address environmental and social determinants of larval habitat proliferation; and educational actions promote local capacity-building and participatory engagement. The integration of these dimensions supports biological control efforts and enhances community health resilience.

The Starting Point: The Complex Problem

The model is activated by the recognized implication of arthropods in public health, specifically mosquitoes of the Order Diptera as vectors of pathogens. It starts from the premise that in contexts of vulnerability, the impact of these diseases is not just a biological issue, but a consequence of interconnected social and environmental determinants, such as limited access to sanitation, clean water, and adequate housing.

The Three Synergistic Pillars and their Interconnections

The Biomedical Approach constitutes the technical backbone of the model. Its function is to provide the scientific foundation through epidemiological surveillance, pathogen diagnosis, and the application of biological control strategies (e.g., use of Bti, larvivorous fish) for the management of larval habitats. However, in this model, its application is not top-down. Instead, its tools and inputs are channeled and contextualized by the other two pillars. For instance, the choice of biological control agent (Biomedical) will depend on the type of larval habitat identified in the community mapping (Ecosocial).

The Ecosocial Approach acts as the contextualizing bridge and source of sustainability. This pillar is responsible for diagnosing and acting upon the environmental and social determinants that favor vector proliferation. Through participatory mapping of breeding sites and analysis of vulnerability, this approach ensures that interventions are not generic but are tailored to the specific reality of the community. It is the realm where community participation is mobilized for concrete action, such as the elimination of containers and the improvement of basic sanitation. It receives technical information from the Biomedical pillar and makes it operable, while being nourished by the educational pillar to empower social actors.

The Educational Approach functions as the engine for behavioral change and empowerment. Its role is to translate scientific knowledge and contextual understanding into practical capabilities for the community. Through training, health promotion, and the formation of community health promoters, this pillar transforms residents from passive recipients of interventions into active agents of their own health. It is the process that ensures the “what to do” (Biomedical) and the “where to do it” (Ecosocial) become an internalized “why and how to do it” for the community.

The Feedback Flow and Sustainability

The essence of the model lies not only in the direction of actions but in the continuous cycles of feedback. Community participation (Ecosocial) generates observations that feed back into and adjust educational messages. Likewise, practical experience in managing larval habitats may indicate the need to reevaluate the biological control strategy (Biomedical). This bidirectional flow makes the model an adaptive and continuously learning system, far from being a static intervention.

The Expected Outcome: Integral Community Health

The coherent implementation of this model leads to an outcome that transcends the mere reduction of mosquitoes. The final product is a strengthened community health ecosystem, characterized by: A tangible reduction in vector density and disease incidence, A healthier physical environment, with fewer larval habitats.

An empowered, resilient community with self-management capabilities, which possesses the knowledge, motivation, and organization to maintain preventive practices over time. This integral model represents a public health paradigm that addresses the biocultural root of vector-borne diseases. By intertwining science, context, and education, it proposes not only to control an epidemic outbreak but to lay the foundations for a healthier, more just, and participatory community.

CONCLUSIONS

Biological control of mosquitoes, especially *Aedes aegypti*, is a key strategy for mitigating the spread of vector-borne diseases such as dengue, zika, and chikungunya. The implementation of biological methods, such as the use of natural predators and aquatic organisms, offers a sustainable alternative to traditional chemical methods that have negative side effects, such as mosquito resistance and environmental pollution. These approaches, which integrate ecological solutions, are essential for addressing public health issues in vulnerable communities.

Research shows that biological control should be considered within a biomedical-ecosocial approach that integrates biological, social, and educational aspects. Vulnerable communities, where sanitation and access to safe drinking water are limited, face greater risks due to the proliferation of mosquito breeding habitats. Through educational strategies and awareness-raising on hygiene practices and environmental management, communities can actively participate in eliminating breeding sites, which enhances the effectiveness of biological control interventions.

Social factors, such as the lack of adequate infrastructure for waste management and water storage, are key determinants in the proliferation of mosquitoes. Interventions should not only focus on physical vector control, but also on improving the social and environmental conditions that favor the creation of larval habitats. In this sense, biological control should be complemented by public policies that promote improved urban infrastructure, efficient resource management, and community education.

Biological control methods, such as the use of predatory fish and copepods, have shown promising results in reducing mosquito populations in different regions. These approaches are more sustainable and less costly compared to the repeated use of insecticides, which carry long-term risks to both the environment and human health. In addition, biological control has the potential to be easily integrated into stagnant water environments, such as those found in rural and peri-urban communities.

It is crucial to continue researching new species of natural enemies and their ability to control mosquito populations in different ecosystems. In addition, the social and economic effects of biological control strategies in vulnerable communities must be further evaluated to ensure that these interventions are accessible and effective in the long term. Collaboration between scientists, governments, and local communities should also be encouraged to develop solutions tailored to local needs and capacities, which will ensure successful implementation.

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