International Platform of Registered Systematic Review and Meta-analysis Protocols

INPLASY

Climate-Driven Modelling of Mosquito Population Dynamics: Protocol for a 10-Year Systematic Review (2015-2025)

INPLASY202640046
doi: 10.37766/inplasy2026.4.0046
Received: 13 April 2026
Published: 13 April 2026

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ADMINISTRATIVE INFORMATION

Support - Wellcome Trust.

Review Stage at time of this submission - Data analysis.

Conflicts of interest - None declared.

INPLASY registration number: INPLASY202640046

Amendments - This protocol was registered with the International Platform of Registered Systematic Review and Meta-Analysis Protocols (INPLASY) on 13 April 2026 and was last updated on 13 April 2026.

INTRODUCTION

Review question / Objective The primary objective of this systematic review is to synthesize ecological modelling studies that assess the abundance, spatiotemporal distribution, or environmental suitability of vector mosquito populations under changing climate conditions, using modelling frameworks such as system dynamics, statistical, machine learning, agent-based, and species distribution or ecological niche models. The review focuses on studies that were published between January 2015 and July 2025. Specifically, our aim is to identify research gaps in global spatiotemporal coverage, evaluate the integration of climatic and environmental predictors, assess the methodological quality and predictive performance of existing ecological models, and evaluate the effectiveness of ecological models in predicting vector abundance distribution and informing vector control strategies.

This systematic review aims to address the following five research questions:
1. What mosquito species and genera are most frequently represented in climate-driven ecological models?
2. Which climatic variables and environmental factors are identified as the primary drivers of mosquito population dynamics?
3. How do different modeling frameworks differ in their ability to predict mosquito vector abundance, phenology, and geographic range shifts globally?
4. What are the prevailing trends in the structure of ecological models and validation techniques in the literature published between January 2015 and July 2025?
5. What are the essential research gaps in current ecological modeling efforts regarding data resolution, multi-decadal projections, and geographical bias?

Rationale Mosquitoes are primary vectors of infectious diseases such as malaria, dengue, Chikungunya, Zika, Rift Valley fever, and yellow fever. Their life cycle and population dynamics are

driven by changing climatic conditions (such as temperature, rainfall, and humidity), land-use patterns, and demographic changes. In the face of global climate change, developing robust ecological models to predict mosquito behavior and distribution is a priority for public health surveillance, evidence-based decision-making, and the design of targeted vector control strategies.
Despite a significant increase in the development of ecological models over the past decade, the field is characterized by substantial heterogeneity in model structure, biological parameterization, and methodological quality. To the best of our knowledge, no systematic review has concurrently synthesized and evaluated the diverse modeling frameworks applied to mosquito vectors specifically within the past decade (2015–2025). This period is important because it marks a global transition toward the use of high-resolution spatiotemporal climate data, the rapid integration of machine learning and artificial intelligence, and the increased adoption of the One Health approach, which integrates human, animal, and environmental health data.

The rationale for this study is two-fold:
1. Methodological Synthesis: There is a pressing need to categorize the evolution of various modelling frameworks (ranging from traditional compartmental and regression models to complex agent-based, machine learning, and ecological niche models) to understand which ones are most effective for specific public health objectives. We hypothesize that methods are being underused in the environmental contexts that they are most suited for.
2. Quality Assessment: Current literature lacks a standardized, comparative evaluation of model credibility and transparency. By applying the TRAnsparent and Comprehensive model Evaludation (TRACE) 2014 framework, this review aims to identify systemic weaknesses in how ecological models are developed, tested, analyzed, and communicated. This will provide a roadmap for improving the reliability of ecological models, ensuring that they serve as high-quality tools for policymakers and health practitioners.

Condition being studied The condition studied in this systematic review is the climate-driven dynamics of vector mosquito populations and the associated risk of mosquito-borne disease transmission. Mosquitoes are biological vectors of pathogens such as arboviruses and parasites, and their population abundance and distribution are sensitive to changing climatic conditions due to their ectothermic nature. Their biological processes, such as reproduction, larval development, adult survival, and pathogen incubation, are influenced by climatic variables (such as temperature, rainfall, humidity), land use, and demographic changes. Temperature regulates mosquito development rates and the extrinsic incubation period of pathogens, while precipitation and humidity determine the availability of aquatic breeding habitats and influence adult survival. Environmental factors such as land cover, vegetation indices, and urbanization patterns further modulate the spatial distribution of mosquito suitability.

This review therefore focuses on suitability and abundance of mosquito vectors as the core condition of interest. Changes in these ecological determinants, under climate variability and climate change, can alter the geographic distribution and seasonal dynamics of mosquito populations, thereby increasing the risk of disease transmission in both endemic and previously unaffected regions.

METHODS

Search strategy A) Databases and Platforms
A systematic literature search was conducted across six major electronic scientific databases to ensure maximum coverage of peer-reviewed computational and epidemiological literature: PubMed, Web of Science, Scopus, SpringerLink, Nature Portfolio, and Google Scholar.

B) Search Date and Temporal Limits
The primary search was executed on 4th July 2025. The search was limited to articles published between January 2015 and July 2025 to capture the most recent decade of advancements in ecological modelling, high-resolution spatiotemporal data, and machine learning (ML) integration.

C) Search Terms and String
The search employed a combination of keywords and Medical Subject Headings (MeSH) terms. The strategy used three primary thematic clusters (Mosquito vectors, Modelling frameworks, and Climate change) joined by the AND operator. The full search string was as follows:

("Aedes" OR "Aedes aegypti" OR "Aedes albopictus" OR "Mosquito*" OR "Culex" OR "Anopheles")
AND ("species distribution model*" OR "SDM" OR "agent-based model*" OR "ABM" OR "rule-based model*" OR "mathematical model*" OR "compartmental model*" OR "mechanistic model*"

OR "ecological niche model*" OR "MaxEnt" OR "simulation model*" OR "system dynamic*")
AND ("climate change" OR "climate variability" OR "temperature" OR "rainfall" OR "precipitation" OR "humidity")

D) Search Strategy Refinement
The search was restricted to English-language, peer-reviewed, full-text journal articles. Initial results were imported into Mendeley for deduplication. The search string yielded an initial total of 1,784 records, which were then subjected to multi-stage screening (Title/Abstract and Full-Text) by three independent reviewers to identify the final 235 eligible studies.

Participant or population The population of interest in this systematic review comprises mosquito vector species and their populations across all geographic regions and ecological zones. The focus is on mosquito population dynamics, abundance, occurrence, density, distribution, and environmental suitability. Emphasis is placed on studies that model these populations and incorporate climate variability.

Intervention The intervention of interest is the application of modelling frameworks used to assess mosquito population dynamics under varying climate conditions. These include system dynamics models, statistical and machine learning models, ecological niche or species distribution models, and agent-based models that incorporate climate variables as predictors. The review evaluates how these modelling approaches are applied to simulate, predict, and understand mosquito population abundance, distribution, and environmental suitability.

Comparator The comparators in this review include alternative modelling frameworks and benchmark standards used to evaluate model performance and quality. Specifically, comparisons will be made across different ecological and computational modelling approaches (e.g., system dynamics models, statistical and machine learning models, species distribution models, and agent-based models) in terms of their structure, integration of climatic and environmental predictors, validation approaches, and predictive performance. In addition, all included studies will be compared against established modelling best-practice frameworks, particularly the TRACE framework (proposed by Grimm et al. 2014), to assess the quality of model development, testing, and analysis across key components such as problem formulation, model description, data evaluation, verification, validation, and model output analysis.

Study designs to be included This review includes peer-reviewed, full-text original journal articles that develop, implement, or validate ecological models of mosquito population dynamics. Eligible designs include system dynamics, statistical and machine learning, ecological niche or species distribution, and agent-based models that incorporate climate variables as predictors.

Eligibility criteria Eligible studies must report clearly defined outcomes that are related to mosquito population dynamics (e.g., abundance, occurrence, distribution, or suitability) and provide sufficient methodological detail on model structure, parameterization, and validation. We will exclude those studies that have incomplete methodological descriptions, inaccessible full texts, focus on non-mosquito vectors, or no climatic predictor(s) and/or modelling frameworks, and those that report disease incidences only without mosquito component or entomological data, prior to 2015, and non-English publications. Where multiple publications report on the same model or dataset, the most recent version will be retained. Additionally, non-peer-reviewed grey literature (e.g., preprints, policy briefs, and reports), conference abstracts, editorials, non-modelling observational studies, and trial registers will also be excluded because these sources often lack sufficient technical detail on model development and validation quality standards.

Information sources The primary information sources for this systematic review are six electronic scientific databases selected to ensure comprehensive coverage of multidisciplinary research: 1) PubMed (for literature on biomedical and life sciences); 2) Web of Science Core Collection (for multidisciplinary high-impact research); 3) Scopus (for extensive coverage of computational and engineering-focused modelling); 4) SpringerLink (for access to technical, mathematical, and environmental sciences); 5) Nature Portfolio (to retrieve high-impact studies in ecological modelling); and 6) Google Scholar (used as a supplementary source to identify additional studies not captured in indexed databases, and to support backward and forward citation tracking).

Main outcome(s) The primary outcomes of this review are (i) methodological quality of ecological models and (ii) patterns in modelling approaches for mosquito population dynamics between January 2015 and July 2025.

A) Primary Outcomes

1. Model quality will be assessed using the TRACE 2014 framework to generate quantitative credibility scores (0–2 per item) across 17 questions, with studies classified into high (≥70%), medium (50–69%), and low (<50%) quality tiers based on the overall percentage scores.
2. Distribution and evolution of modelling frameworks: we will conduct a longitudinal analysis of the transition from traditional compartmental and regression models to advanced agent-based models and machine learning integrations over the 10-year period.
3. Spatiotemporal coverage of studies: we will develop a heatmap of the spatial focus of modelling studies against actual published risk maps to identify regions with high abundance (e.g., the Horn of Africa) that are currently underserved by high-resolution predictive frameworks.
4. Identification of geographical and data gaps in ecological modelling: we will develop a heatmap of locations with and without associated data over time to identify differences and gaps in ecological modeling intensity.

B) Secondary Outcomes

1. Predictor integration: The frequency and methods by which climatic factors (such as temperature, precipitation, humidity), socioeconomic indicators, and demographic variables are incorporated into ecological models as covariates.
2. Level of biological complexity represented in ecological models: The proportion of models that incorporate advanced features such as mosquito diapause, survival, density-dependent mortality, etc.
3. Application of ecological models for decision support in vector control: Evaluation of models used specifically for vector control simulation to provide evidence-based public health decision-making.

C) Timing and Measures

Outcomes will be synthesized using descriptive statistics (e.g., frequencies, proportions) and trend analyses, using Python software. The results will offer a baseline for identifying systemic gaps in ecological modelling.

Additional outcome(s) None.

Data management The data management process for this systematic review is designed to ensure transparency, reproducibility, and efficient multi-user collaboration. The workflow consists of four main stages.

First, record organization and deduplication, where all search results from the electronic database will be exported in RIS format and then imported into Mendeley reference management software. Automated deduplication will be performed using Mendeley's duplicate detection function, followed by manual verification to remove retracted articles and non-eligible records like conference papers, and book sections.

Second, screening and selection, where title/abstract and full-text screening will be conducted using a shared Mendeley library that is accessible to all three independent reviewers. Decisions for inclusion or exclusion will be documented using Mendeley tags and folders. Discrepancies between reviewers will be resolved through group discussion and consensus.

Third, data extraction and quality assessment, where secondary data will be extracted using a standardized, multi-sheet Excel template hosted on a secure cloud platform (OneDrive) to enable real-time collaboration and version control. The template will capture study metadata, modelling characteristics (e.g., framework, predictors, biological features), and methodological quality based using the TRACE 2014 framework.

Finally, data analysis and storage, where the cleaned secondary dataset will be exported in CSV file for descriptive statistical analysis in Python (via Google Colab). All extracted datasets, analysis scripts, and supporting materials (e.g., PRISMA flow chart) will be securely archived to ensure reproducibility and facilitate future updates.

Quality assessment / Risk of bias analysis The methodological quality of the included studies will be assessed using the TRAnsparent and Comprehensive model Evaludation (TRACE) framework that was proposed by Grimm et al. (2014). This framework is selected because of its robustness in evaluating ecological models across eight critical elements: i) Problem formulation, where we assess the decision-making context, stakeholders or model users, model questions and outputs, and domain of applicability and generalization; ii) Model Description, where we assess the availability of a clear written description of what the model is, how it works, and what guided its design; iii) Data evaluation, where we assess the data sources and scope, data quality and uncertainty, and use of data in model design and parameterization; iv) Conceptual model evaluation, where we assess the simplifying assumptions underlying the model's design; v) Implementation verification, where we assess computer code testing, consistency with model description, and software design and documentation; vi) Model output verification, where we assess model fit to observed data and the role of calibration and environmental drivers; vii) Model analysis, where we assess the sensitivity of model output to changes in model parameters, and the understanding of model behaviour; and viii) Model output corroboration, where we assess the structural realism of the model.

Each study will be evaluated against 17 criteria derived from these TRACE elements. For each criterion, reporting quality will be scored on a scale of 0–2 (0 = not reported, 1 = partially reported, 2 = fully reported), with N/A assigned where appropriate. A cumulative credibility score will be calculated as a percentage of the maximum possible score based on applicable criteria. Studies will then be categorized into three quality tiers: high quality (≥70%), indicating robust and transparent model development and validation; medium quality (50–69%), indicating moderate methodological reporting with some gaps; and low quality (<50%), indicating substantial limitations in transparency and documentation.
The assessment will be conducted by three independent reviewers, with discrepancies resolved through discussion and consensus, and verification by additional co-authors to minimize subjectivity. The scores will not be used to exclude studies but to contextualize the reliability of the findings and help identify systemic gaps in current ecological modelling frameworks.

Strategy of data synthesis Due to the inherent heterogeneity in modelling frameworks, study designs, and reported outcomes, a formal meta-analysis is not technically feasible for this systematic review. Instead, a combination of narrative synthesis and descriptive statistical analysis will be used to systematically characterize the current state of mosquito population modelling studies.
Quantitative synthesis will involve descriptive statistical analyses performed using Python (via Google Colab). Frequencies and proportions will be calculated to summarize key study characteristics, including the distribution and temporal trends of modelling frameworks, the integration of climatic, environmental, and socioeconomic predictors, the representation of biological parameters (e.g., diapause, survival, density dependence), and the distribution of methodological quality scores based on the TRACE framework.

Narrative and thematic synthesis will be used to interpret patterns across studies. This will include identifying methodological gaps by comparing modelling frameworks across geographic regions, assessing the alignment between modelling intensity and known areas of mosquito abundance (ecological zones) or disease hotspots such as the Horn of Africa, and evaluating how models are applied to support vector control and public health decision-making.

Research findings will be presented using structured summary tables and graphical visualizations, including temporal trend plots, geographic heatmaps, and comparative charts of modelling frameworks and quality scores. This integrated approach will provide a transparent and reproducible synthesis of current ecological modelling practices and highlight key research gaps in mosquito population modelling.

Subgroup analysis To address heterogeneity across included studies and identify specific research gaps, subgroup analyses will be conducted across four primary dimensions.
First, by mosquito genera: studies will be grouped by major vector genera (e.g., Aedes, Anopheles, Culex) to assess differences in modelling frameworks, predictor selection, and geographic coverage, and to identify any imbalance in research focus.
Second, by modelling framework: studies will be grouped according to modelling approaches (system dynamics, agent-based, statistical and machine learning, and ecological niche or species distribution models) to compare their application, predictor integration, and suitability for different research or public health objectives.
Third, by methodological quality: using TRACE 2014 framework, studies will be classified into high (≥70%), medium (50–69%), and low (<50%) quality tiers to evaluate whether certain modelling frameworks or geographic regions are associated with higher methodological rigor and transparency.
Fourth, by geographic region: studies will be categorized by geographic location (e.g., continents and country level analyses) to assess spatial disparities in modelling efforts and to identify underrepresented regions or nations relative to known mosquito abundance or disease risk.
These subgroup analyses will be synthesized using descriptive statistical comparisons and visualizations to highlight patterns, inconsistencies, and gaps in current ecological modelling of mosquito populations.

Sensitivity analysis Sensitivity analyses will be conducted to assess the robustness of the qualitative and descriptive findings and to evaluate the influence of key methodological decisions. Two main approaches will be applied to address potential sources of bias and variation.

First, inter-rater reliability and consensus: to minimize selection and extraction bias, a subset of studies will be independently screened and assessed by multiple reviewers. Agreement between reviewers will be evaluated by comparing inclusion/exclusion decisions and the extracted data. Discrepancies will be resolved through structured discussion and consensus, ensuring that the final set of included studies represents a consistent and reproducible sample.

Second, quality scoring thresholds: the categorization of studies into high (≥70%), medium (50–69%), and low (<50%) quality tiers based on TRACE scores will be tested for sensitivity by varying threshold cut-off points by, say ±5%. This will determine whether the observed patterns in methodological quality and identified gaps are robust to changes in classification criteria.

Language restriction Yes, the search is limited to English-language publications only.

Country(ies) involved Kenya, Ethiopia, Somalia.

Other relevant information This systematic review is conducted as part of the ARBO-WATCH project (Modelling dengue and chikungunya transmission patterns for improved public health decision-making in the Horn of Africa), funded by the Wellcome Trust (Grant Number: 308803/Z/23/Z). The review aims to provide a rigorous evidence base to support the development of process-based mechanistic models and decision-support tools tailored to the Horn of Africa (Kenya, Ethiopia, and Somalia).

The specific objectives of this review are to:
(i) identify high-quality parameterization approaches for mosquito population dynamics, particularly for Aedes aegypti and Aedes albopictus;
(ii) evaluate which modelling frameworks are most suitable for capturing climatic, environmental, and socioeconomic drivers that are relevant to the Horn of Africa; and
(iii) strengthen the linkage between ecological modelling and public health surveillance within a One Health framework.

The study is undertaken by a multidisciplinary consortium comprising of ten institutions drawn from Kenya, Ethiopia, Somalia, and United States:
1. Ethiopia Public Health Institute (EPHI)
2. Kenya National Public Health Institute (NPHI)
3. Kenya Medical Research Institute (KEMRI)
4. Kenya Meteorological Department (KMD)
5. Somalia's Federal Ministry of Health (FMoH)
6. Jomo Kenyatta University of Agriculture and Technology (JKUAT)
7. Abrar Research and Training Centre (ARACHTI)
8. Ohio State University (OSU)
9. Global One Health Initiative (GOHi)
10. International Livestock Research Institute (ILRI)

The lead institution is ILRI and the project duration is three years (starting from February 2025 to January 2028). The teams have been using Microsoft OneDrive for research collaboration, which is hosted by ILRI. The findings of the ARBO-WATCH project will contribute to the development of a cross-border, data-driven decision-support system for arbovirus control in the region. The funder has no role in the design, data collection, analysis, interpretation, or reporting of this review. All views expressed in this protocol are solely those of the authors.

Keywords Mosquito population; Climate change; Ecological modelling; Machine learning; Species distribution models; Agent-based models; system dynamics models; statistical models; TRACE framework.

Dissemination plans The findings of this systematic review will be disseminated through a multi-channel strategy targeting both academic researchers and public health stakeholders. First, the primary output will be a peer-reviewed, open-access journal publication to ensure broad accessibility of results and supplementary materials. Second, research findings will be presented at relevant international and regional scientific conferences to engage the research community. Third, policy briefs and institutional reports that summarize key modelling gaps and best practices will be shared with stakeholders and decision-makers, particularly within the Horn of Africa. Fourth, the standardized data extraction Excel file and python analysis scripts will be made publicly available through open-access repositories (such as GitHub, Figshare, Zenodo, or Dryad) to promote research transparency and reproducibility. Finally, the identified high-quality studies will be used as benchmarks for best practices in ecological modelling and to support capacity-building activities within the ARBO-WATCH consortium, including training workshops for graduate researchers and public health practitioners that are part of the consortium.

Contributions of each author

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