Increase, decrease, or both: A systematic review of mosquito population response to floods

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Abstract

Floods are increasing in frequency and severity under the ongoing climate change and are widely reported to alter mosquito population dynamics. However, the direction, magnitude, and consistency of this effect across mosquito species and flood contexts remain poorly studied. This systematic review synthesizes empirical evidence on mosquito species population responses to disastrous flood events and identifies environmental and flood-specific factors that modulate these responses. Scopus, Embase, and PubMed were searched following PRISMA guidelines for English-language articles reporting empirical mosquito population data in relation to unexpected, disastrous flooding. Articles addressing seasonal, tidal, or controlled flooding were excluded, as were those reporting only mosquito-borne disease outcomes or indirect population proxies. Of 2,005 records identified, 28 studies met the inclusion criteria, spanning 1970–2025 (most published since 2020) and 12 countries, with a strong bias toward the USA (35.7% of studies) and no studies from South America or Southeast Asia. Most studies (78.6%) reported a population increase in at least one species following flooding, while over a third (35.7%) reported a decrease, and several documented both patterns across different species. Floodwater species showed comparatively consistent post-flood increases, whereas responses among non-floodwater species were inconsistent across studies. Flooding substantially affects mosquito abundance, species composition, and assemblage structure, but no single, generalizable direction of effect exists. Responses are shaped by species identity, flood properties, environmental context, vector control, and study design. Rainfall, temperature, and standing water were the most frequently implicated modulating factors, alongside flood depth and duration. Geographically diverse, standardized, high-resolution surveillance, combined with rigorous statistical and modeling approaches, is needed to better anticipate flood-driven vector risk under a changing climate.

1 Introduction

Mosquito ecology is shaped by a broad range of environmental drivers, among which temperature, precipitation, and humidity are particularly influential, affecting development rates, survival, reproductive success, and geographic distribution [8, 9, 38, 48]. Climate change is increasingly recognised to significantly impact mosquito ecology, operating through two interacting pathways. First, gradual shifts in baseline conditions are altering the seasonal timing and spatial extent of suitable mosquito habitat [17, 29]. Second, climate change is projected to increase both the frequency and magnitude of extreme weather events [27, 13, 36], including floods and storms, which have been reported to trigger acute and often dramatic changes in mosquito population dynamics [14]. Among extreme weather events, floods are of particular concern: their frequency and severity have increased over the recent decades [36, 4, 16], and they carry distinct consequences beyond immediate physical hazards in terms of vector control and changes to the ecological landscape beyond mosquitoes [25, 21, 12, 52, 15]. Many floodwater mosquitoes lay eggs on moist soil rather than directly on standing water [6]. These eggs can enter a dormant state and survive for months, sometimes even years, under dry conditions [6]. A single flooding event synchronously hatches vast numbers of eggs that have been accumulating in the soil for months or even years. This is the primary driver of mass population increase in temperate riverine zones [7, 55]. This "egg bank dynamic" may explain why exposion in mosquito population often follow years of drought or below-average flooding, conditions that prevented previous hatching while allowing eggs to accumulate, and is a key reason simple rainfall-based forecasting models may underestimate outbreak size. However, fast-flowing floodwater simultaneously causes the washout of existing breeding sites, physically displacing eggs, larvae, and pupae from the water bodies they normally occupy; species belonging to the *Culex* genus are particularly vulnerable to this effect, as they lay eggs directly on water surfaces as floating rafts [41, 46]. Beyond hydrology, floodwaters transport organic matter, sediment, and organisms that reshape the biotic environment in which larvae develop. Elevated nutrient loads can accelerate larval development, but may equally favor competing filter-feeders or trigger algal blooms that impair water quality, making the net effect on larval survival difficult to predict without detailed habitat-level information.

The existence of all these competing mechanisms at play in the aftermath of a flood give rise to three research questions addressed by this systematic review. First, which studies have *empirically* quantified mosquito population abundance after flood events, and what do their findings collectively show? Second, are flood events consequences species-specific? Do floods primarily drive outbreaks of floodwater species such as *Aedes vexans*, or do non-floodwater disease vectors also respond significantly to flood conditions? Third, which environmental and flood-specific factors, such as magnitude, duration, and landscape context, modulate the population response, and do they account for the heterogeneity observed across studies?

To address these questions, this review identified studies measuring mosquito population responses following unexpected flood events.

2 Methods

On May 05 2025, Scopus, Embase and PubMed have been searched on title, abstract and keyword level with the following search string targeting flood events and mosquito population:

(flood* OR inundat* OR ((water* OR hydro*) AND (disaster OR "extreme event")) OR ((rain* OR precipitation*) AND (heavy OR extreme)) OR (hurricane OR typhoon OR cyclone))

AND

((mosquito* OR culicidae OR anopheles OR aedes OR ochlerotatus OR culex OR mansonia OR psorophora) AND (population OR occurrence OR abundance OR density OR surveillance))

Where * signifies any possible extensions of the corresponding word. Encompassing related terms such as "heavy rain" and extreme weather events (e.g. hurricanes) as well as taxonomic terms including the family name *Culicidae* and several key genera broadens the scope of retrieved articles.

Deduplication process was performed in EndNote 2025 [1] following the deduplication strategy of [10]. Two authors (TR and PC) did title and abstract screening, while conflicting assessment was resolved by a third (DDR). The same procedure was implemented for full text screening. After full text screening, the cited references of the retained articles were compiled for screening on title, abstract and full text level.

Articles had to meet the following inclusion criteria: i) the flood must be unexpected and potentially disastrous in nature, excluding seasonally regular flood events, with the aim of focusing on rare, episodic occurrences; ii) the article must report data on mosquito population (indirect proxies such as landing rates or household indices were not considered suitable);iii) mosquito population has to be discussed in relation with the flood (articles discussing the two separately were not retained); iv), only scientific articles in English were considered. No requirements concerning the geographic origin or publishing/study time were applied. Conversely, the exclusion criteria are presented in Table 1.

Data extraction was guided by a predefined table of variables, developed based on established literature and the specific focus of this review by three authors (TR, DDR, PC). One author (TR) performed the data extraction, with two other authors (DDR and PC) having checked the table for consistency and adherence to the original papers. Extracted information included general study characteristics such as country, year of the flood, and years of data collection (recording each year in which at least one data point was collected). Furthermore, the time resolution of each study, i.e. the shortest time period used in the analysis or data collection (e.g. weekly, monthly, yearly) is given.

The effect of flooding on mosquito populations is captured through four non-

Category	**Exclusion Criteria**
Mosquito	No mosquito data (occurrence, abundance, surveillance etc.)
	Discussion of mosquito-borne disease only
	Pure discussion of habitat suitability
Flood	Flooding without disastrous character
	Heavy rain without inundation
	Hydrophilic situations with water as integral part of the land's characteristics (e.g., seasonal wet-land, swamps, natural river delta, wash-land, tides, marshes)
	Controlled flooding/inundation (e.g., rice fields)
	Recurrent/seasonal/tidal flooding
Flood & Mosquito	No combination/intertwined analysis of flood and mosquito dynamics
Articles	Not English
	Not an article (but e.g. conference abstract)

Table 1: Exclusion criteria

mutually exclusive categories. An increase (↑) indicates that at least one species was reported as increasing in abundance, while a decrease (↓) indicates a reported reduction in at least one species. A third category, "non zero", was assigned to one study that reported a statistically significant difference in abundance without specifying its direction. Finally, the ↑ / ↓ category denotes a species that first increased and subsequently decreased (denoted *increase & decrease dynamics*). Because these categories apply at the species level, all four may be recorded simultaneously for a single study if different species exhibited different responses. Where statistical testing was performed to assess the significance of a reported effect, the corresponding symbol is marked with the sign $^{+}$. The time lag between the flood event and the reported impact on mosquito populations (e.g. "increase after 4 weeks") was extracted and recorded verbatim, without aggregation.

Additionally, named environmental factors like temperature or rain and in particular flood properties like flood duration are reported if they are stated to impact mosquito population. They are marked with a * if the study explicitly stated those factors to modulate the flood's effect on mosquito population.

For mosquito taxonomy, the genus of each reported species is provided. A dedicated column indicates whether floodwater mosquito species were present among those reported (Yes) or not (Not). Classification of floodwater species was based on a reference list compiled from [6] and [54], taking the union of the floodwater species identified across both sources.

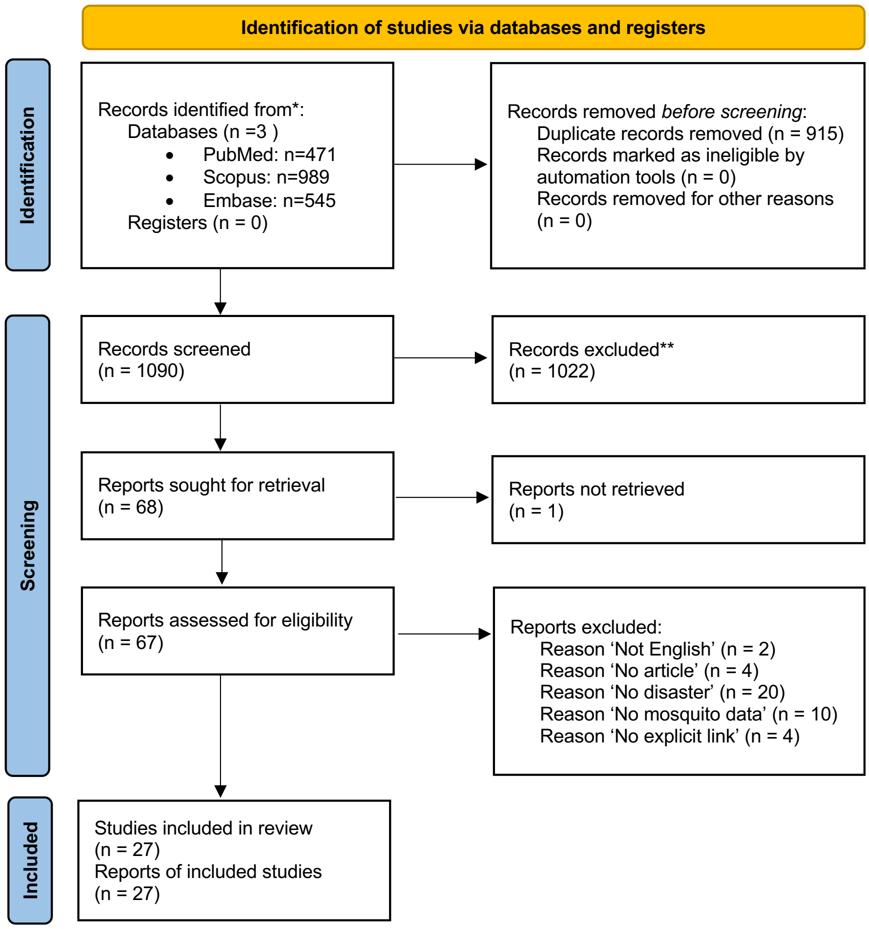

Figure 1: Diagram showing the search and screening results following the PRISMA (Preferred Reporting Items for Systematic reviews and Meta-Analyses) guidelines [44].

3 Results

3.1 Review results – overview

The initial search of the main databases retrieved a total of 2005 articles. After removing 915 duplicates, 1090 articles were kept for title and abstract screening, of which 1022 were excluded, leaving 68 articles for full-text screening. Among those, 27 studies were selected for inclusion. An additional study was found by screening the references of these studies. Finally, 28 papers are included in this review. Table 2 summarizes the characteristics of each study, including authors and year, country, dates of flood events and mosquito data collection

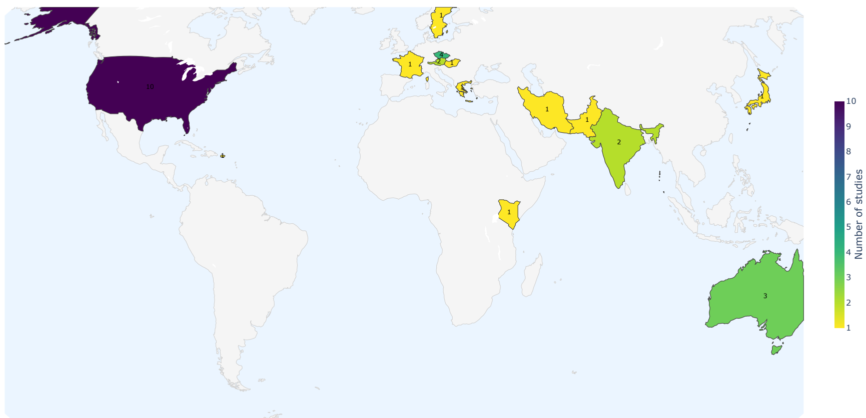

Figure 2: Number of studies per country.

with the corresponding time resolution, the main effects reported (increase, decrease etc.), following the methodology and definitions of Section section 2. Furthermore, it states the time lag of the effect on mosquito population, the interfering environmental factors, and the properties of the flood. Lastly, the table also specifies whether floodwater mosquito species were included, and reports the examined genera.

3.2 Temporal and geographic study distribution

The earliest selected article was published in 1970 [22]; all remaining studies were published after 1990, with the most recent six years (2020-2025) being the most represented (Figure 4, a). The most common study country was the USA (studies, 35.7%), and the vast majority of studies (studies, 92.9%) focused on a single country. Most studies (studies, 71.4%) collected data across more than one year, whereas all but two [11, 20] examined floods occurring within a single year. Data was reported with different time resolutions, with 10 studies (35.7%) reporting data every week, 3 studies (10.7%) every two weeks,1 study (3.7%) every 3 weeks and 4 studies (14.3%) every month. Five studies had longer time intervals between data collections, with 2 studies (7.1%) reporting data every four months and 3 studies (10.7%) reporting data every year. Two studies trap mosquitoes daily, but only for a short period (e.g. [40]: one week before and one after the extreme event). Three studies (10.7%) collected data only at one time point.

3.3 Increasing/decreasing effect on mosquito population

Most papers (studies, 78.6%) reported an increase in the population of at least one species, with 12 studies (42.9%) supported this with a statistical test. In contrast, 10 studies (35.7%) reported a decrease, with 5 studies (17.9%)

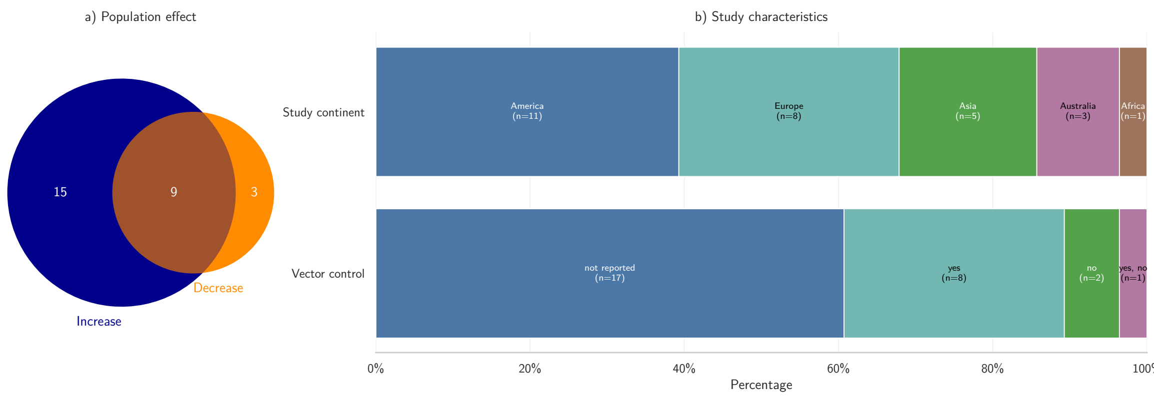

Figure 3: Impact of floods on mosquito population (panel a) and study characteristics such as study continent, presence of vector control measures (panel b).

reaching statistical significance. Two studies [37, 53] documented competing temporal effects, with an initial increase followed by a subsequent decrease (increase & decrease dynamic). One study reported a statistically significant difference in mosquito abundance before and after the flood without specifying its direction [19]. These effects were associated with varying time-lags, broadly falling into two categories: within 1 to 5 weeks after the flood (studies, 46.4%) or approximately one year after (studies, 14.3%), with one study documenting both [37]. An additional 12 studies (42.9%) did not report any time-lag.

3.4 Interplay influencing environmental factors

Several factors were identified as influencing the flood-mosquito interaction (see Table 2). The most commonly reported factor was rain (studies, 64.3%), followed by temperature (studies, 46.4%), standing water (studies, 35.7%), humidity (studies, 21.4%), and degree of urbanity (studies, 14.3%). Vector control (studies, 10.7%) and previous or adjacent flooding (studies, 7.1%) were also noted. A total of 4 studies (14.3%) did not report any factors. Additionally, Table 2 also shows flood properties that can modulate the effect of the flood on the mosquito population. While 13 studies (46.4%) did not explicitly mention flood properties, 7 studies (25%) report the flood depth and 5 studies (17.9%) flood duration as important aspects. Furthermore, the spatial flood extent (studies, 14.3%) and its timing (studies, 14.3%) are mentioned as relevant factors. Two studies reported properties like water salinity or water quality as important.

3.5 Reported mosquito species, life stages and mosquito traps

In total, 16 different genera are found among the selected studies, with *Aedes*, *Culex* and *Anopheles* being mentioned in 23 studies (82.1%) , 23 studies (82.1%)

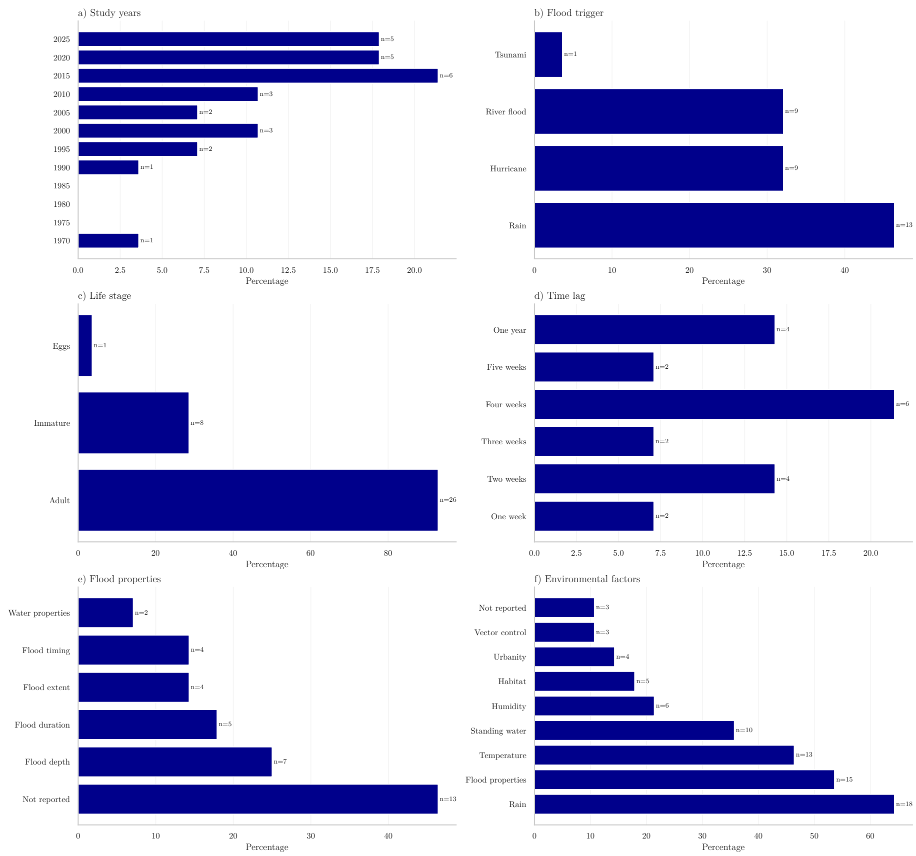

Figure 4: Study characteristics: study year (panel a), flood trigger (panel b), life stages studied (panel c), time lags reported (panel d), flood properties reported (panel e) and environmental factors (panel f).

and 19 studies (67.9%) respectively. Floodwater mosquito species were included in 18 studies (64.3%) . In total there were roughly 200 species reported, with five being reported more than five times: *Culex quinquefasciatus* (studies, 42.9%), *Aedes vexans* (studies, 35.7%), *Culex pipiens* (studies, 25%), *Aedes aegypti* (studies, 21.4%) and *Aedes sticticus* (studies, 21.4%). A variety of trapping methods were employed across the included studies. The most frequently used were baited light traps used in 7 studies (25%) , followed by dippers and mechanical adult collection, each reported in 6 studies (21.4%) . BG traps, EVS traps, and non-baited light traps were less common, each appearing in 4 studies (14.3%) . 3 studies (10.7%) did not report the trapping method used.

3.6 Species-specific flood effects

Several studies reported species-specific effects; we selected the most significant that we report here separately for floodwater mosquitoes (*Ae. vexans* and *Ae. sticticus*) and non-floodwater mosquitoes (*Ae. aegypti*, *Cx. quinquefasciatus*, *Cx. nigripalpus*, *Ae. albopictus*, and *Cx. tarsalis*).

3.6.1 Floodwater mosquitoes

Aedes vexans is discussed in several articles [7, 22, 30, 55, 51]. Four consistently report post-flood increases in adults and larvae [7, 30, 51] or the emergence of a new generation in warm autumn conditions that extended the mosquito season [55]. The exception is Hajkova et al. [22], who reported a population decline following the 1965 flood, attributed to high streaming water levels persisting at the time of larval hatching. *Aedes sticticus* was covered in three articles, consistently showing post-flood increases: either a rise in abundance four weeks after the flood [7] or attainment of dominant or most abundant species status [22, 47].

3.6.2 Non-Floodwater mosquitoes

Aedes aegypti increased following hurricanes [5, 53] and showed higher abundance in flood years [42]; however, Macdonald et al. [34] found no population response to standing water in the inundation's aftermath. The same study reported a similarly absent response for *Culex quinquefasciatus* [34], which nonetheless increased significantly following hurricanes Harvey [25] and Irma [37, 53]. Hurricane Irma also drove increases in *Culex nigripalpus* [37, 53]; this species additionally accounted for more than 75% of mosquitoes collected after Hurricane Katrina, a striking contrast with its prevalence of less than 1% recorded during surveillance in a neighboring area over the preceding four years [18]. *Aedes albopictus* was likewise affected by Hurricane Irma, with large numbers produced in its aftermath [53], and adult female density increased four weeks after flooding in Montpellier, France [46]. Finally, conflicting results have been reported for *Culex tarsalis*: Mori et al. [39] found that river flooding reduced mosquito numbers, whereas MacDonald et al. [34] find the same species to be increased significantly following flooding.

Table 2: Summary of included studies

Study	Study country	Flood (year)	Data collection (year)	Data resolution	Effect	Time lag	Environmental factors	Flood properties	Floodwater mosquito	Genus
Barrera et al. [5] (2019)	Puerto Rico	2017	2016-2018	1 week	$\uparrow^{+}$ $\downarrow^{+}$	5 weeks	temperature rain humidity vector control urbanity infrastructure standing water	–	No	Aedes Anopheles Culex Mansonia Psorophora Uranotaenia
Berec et al. [7] (2014)	Czech Republic Austria	2009	2008-2011	2 weeks	$\uparrow^{+}$	4 weeks	temperature* rain habitat	flood depth*	Yes	Aedes
Broom et al. [11] (2003)	Australia	1981 1991 1993 1997 2000 2001	1989-2001	1 year	$\uparrow$	–	rain	flood extent*	Yes	Aedeomyia Aedes Anopheles Culex Tripteroides
Foppa et al. [18] (2007)	USA	2005	2005	–	$\uparrow$	–	–	–	Yes	Aedes Anopheles Culex Psorophora
Fricker et al. [19] (2025)	Australia	2010	1999-2019	3 weeks	non zero^{+}	1 year	habitat	–	Yes	Aedes Anopheles Coquillettidia Culex Mansonia Tripteroides
Gicheru et al. [20] (2021)	Kenya	2011 2014	2012-2013	1 month	$\uparrow$ $\downarrow$	–	–	flood depth	No	Coquillettidia Culex Mansonia more_not_specified
Gilliland et al. [21] (1995)	USA	1993	1993	1 week	$\uparrow^{+}$	–	standing water rain	–	Yes	Aedes Anopheles Coquillettidia Culex Culiseta Orthopodomyia Psorophora Uranotaenia

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Study	Study country	Flood (year)	Data collection (year)	Data resolution	Effect	Time lag	Environmental factors	Flood properties	Floodwater mosquito	Genus
Hajkova et al. [22] (1970)	Czech Republic	1965	1962-1966	2 weeks	$\downarrow$	1 year	temperature rain standing water	flood extent flood timing flood depth	Yes	Aedes Anopheles Culex Culiseta Mansonia
Huang et al. [25] (2023)	USA	2017	2016-2017	4 months	$\uparrow^{+}$	–	temperature rain	–	No	Culex
Hubálek et al. [26] (2000)	Czech Republic	1997	1997 1999 2000	1 year	$\uparrow$	–	–	–	Yes	Aedes Anopheles Culex Culiseta
Khan et al. [28] (1996)	India	1991	1991-1992	2 weeks	$\uparrow^{+}$ $\downarrow^{+}$	4 weeks	rain temperature* humidity	flood depth	Yes	Aedes Anopheles Armigeres Culex Mansonia
Kuroli et al. [30] (2002)	Hungary	1999	1999	1 week	$\uparrow$	1 week	temperature* habitat standing water*	flood depth flood duration*	Yes	Aedes Anopheles Chaoborus Chironomidae Culex Culiseta Uranotaenia
Lucas et al. [31] (2019)	USA	2017	2016-2018	1 day	$\uparrow^{+}$ $\downarrow^{+}$	1 year	rain	flood depth	Yes	Aedes
MacDonald et al. [34] (2025)	USA	2023	2022-2023	1 month	$\uparrow^{+}$	–	humidity urbanity standing water*	flood duration*	No	Aedes Culex
Mathur et al. [35] (1992)	India	1990	1989-1990	1 year	$\uparrow$ $\downarrow$	–	rain urbanity standing water	–	No	Anopheles

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Study	Study country	Flood (year)	Data collection (year)	Data resolution	Effect	Time lag	Environmental factors	Flood properties	Floodwater mosquito	Genus
Moise et al. [37] (2024)	USA	2017	2016-2018	1 week	$\uparrow^{+}$/$\downarrow$	1 week 3 weeks	temperature rain human population density	–	Yes	Aedes Anopheles Coquillettidia Culex Deinocerites Mansonia Psorophora Uranotaenia Wyeomyia
Mori et al. [39] (2018)	USA	2011	2007-2016	1 week	$\downarrow^{+}$	2 weeks 1 year	temperature humidity	flood depth*	No	Culex
Morrow et al. [40] (2010)	Belize	2008	2008	1 day	$\uparrow^{+}$ $\downarrow^{+}$	–	–	–	Yes	Anopheles Culex Aedes Coquillettidia Mansonia Psorophora
Mourelatos et al. [41] (2025)	Greece	2023	2021-2023	1 week	$\uparrow^{+}$	2 weeks 5 weeks	rain temperature	flood extent* flood timing	Yes	Aedes Anopheles Culex
Nasir et al. [42] (2017)	Pakistan	2010	2009-2013	4 months	$\uparrow$	–	humidity urbanity rain standing water* temperature	water properties	No	Aedes
Neville et al. [43] (2025)	Australia	2022	2022-2023	1 week	$\uparrow$	2 weeks	temperature rain	flood duration flood timing	No	Aedes Anopheles Culex
Roiz et al. [46] (2015)	France	2014	2014	1 week	$\uparrow^{+}$	4 weeks	humidity temperature* rain* standing water	–	No	Aedes
Schäfer et al. [47] (2008)	Sweden	2000	2000-2002	1 month	$\uparrow^{+}$	4 weeks	species influx rain previous/adjacent flooding habitat	–	Yes	Aedes Anopheles Coquillettidia Culex Culiseta

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Study	Study country	Flood (year)	Data collection (year)	Data resolution	Effect	Time lag	Environmental factors	Flood properties	Floodwater mosquito	Genus
Šebesta et al. [55] (2016)	Czech Republic Austria	2014	2009-2011 2013-2014	1 month	↑	4 weeks	temperature* rain previous/adjacent flooding standing water	flood timing flood duration	Yes	Aedes Anopheles Coquillettidia Culex
Sofizadeh et al. [49] (2025)	Iran	2019	2019	–	↓	4 weeks	vector control habitat	–	Yes	Aedes Culex Culiseta Uranotaenia
Tsuda et al. [50] (2013)	Japan	2011	2011	–	↑+	–	standing water	water properties	No	Anopheles Culex
Vigilant et al. [51] (2020)	USA	2017	2017	1 week	↑ ↓	–	rain vector control	–	Yes	Aedes Anopheles Coquillettidia Culex Mansonia Orthopodomyia Psorophora Toxorhynchites Uranotaenia
Weaver et al. [53] (2020)	USA	2016	2016 2017	1 week	↑/↓	2 weeks 3 weeks	rain	flood extent flood duration	Yes	Aedes Anopheles Coquillettidia Culex Culiseta Psorophora Uranotaenia

4 Discussion

Several reviews have recently syntetized the impact of climate change on mosquito populations, focusing for example on range shifts [32] or environmental drives [3], but none, to the best of our knowledge, focused specifically on the impact of flooding events. Although biological considerations can provide an answer to the question "what is the impact of floods on mosquito populations", in this systematic review we attempted to answer this question by identifying articles that provided mosquito population data to quantify this effect. What we found is a rather complex interplay between mosquitoes and floods, which depends on several factors and, most importantly, on the species considered.
Among the retained studies, all but one were published after 1990, with the highest number of articles published within the last six years. This may be due to several factors such as, among others, the increase in the availability and accessibility of mosquito surveillance material and the increasing resources devoted to mosquito surveillance, especially in relation to mosquito-borne diseases. However, it may also highlights a rising interest in the impact of extreme events on mosquito population, especially in terms of their implication for public health [14]; given the increasing trends in terms of frequency and severity of extreme events under the effect of climate change [36, 27] we can expect this field to become more prominent in providing risk assessment and guiding surveillance and vector control strategies.

Our review also highlighted a strong geographical bias of the selected studies, with more than one third of them focusing on the USA and only a few countries (Australia, Czech Republic, India) being the target of more than one study. This distribution is clearly not representative of the underlying risk of floods [2, 45], in particular with no studies for South America or Southeast Asia, and very limited coverage of Africa. This resulting geographical bias has further implications for the future, as flood frequency will increase due to climate change primarily in Southeast Asia, Peninsular India and eastern Africa [24].
Although the selected articles showed considerable heterogeneity in terms of sampling methodology, data collection method and overall scope, we attempted to aggregate the reported effects on mosquito populations as much as possible. The majority of studies reported an increase in the mosquito population of one or more species. This population increase is sometimes quantified: For instance, [37] reports a 7.3- or 8-fold increase in the mosquito population after Hurricane Irma compared with the preceding or following year, respectively. In other cases, this increase is only reported in qualitative terms as the increase or the amplification of one species (e.g. *Cx. quinquefasciatus* [25] or *Ae. vexans* [55]) or of overall mosquito abundance (e.g. in [46, 41]). At the same time, one-third of the studies reported a decrease in at least one species. For example, [22] describes a substantial reduction in the abundance of the dominant species *Ae. vexans*, while [39] reports a decrease in *Cx. tarsalis*. Scientific literature commonly mentions the effect of an initial decrease in mosquito population after a flood, followed by a subsequent increase [6]. Initially, larvae and eggs are assumed to be flushed away, resulting in lower mosquito counts, whereas

mosquito populations are expected to increase after a certain time lag (a *decrease & increase dynamic*). Although this effect is commonly mentioned also among our selected studies [22, 35, 49, 51], only two measured similar temporal patterns. The study of Moise et al. [37] founds an increase during the first week after Hurricane Irma, followed by a decrease over the subsequent two weeks and a final increase three weeks after the Hurricane. With similar timing, Weaver et al. [53] report low mosquito counts during the first two weeks after the hurricane and increased counts after three weeks. Indeed, to identify these effects a weekly or bi-weekly temporal resolution is needed, as a coarser temporal resolution would not allow it to be appreciated. In general, annual or monthly mosquito counts were commonly used, reducing the possibility to observe this effect, but with the advantage of limiting the effect of short-term fluctuations [21] and the further drawback of hiding small differences in the onset of the mosquito season. Nevertheless, from our study it can be concluded that the effects of flooding on mosquito populations can be observed from a few weeks to up to at least one year after the flooding event. In addition to sub-monthly time resolution, to observe the effects of floodings is also necessary that the surveillance network is not hindered by the flood itself: this was the case for several studies we selected, where data collection was interrupted in the short aftermath of the flood, further reducing the pool of studies that could have measured this decrease & increase dynamic in mosquito population. From the methodological perspective, roughly half of the selected studies make use of statistical methods, with increases being assessed statistically more than decreases. A wide range of methods was applied, ranging from the simple reporting of means and standard deviations to different forms of regressions, analysis of variance (ANOVA) and other methodologies. This heterogeneity in methodological approach may stems from different choices, focus, and data specifics, and indeed limits the quantitative comparisons between studies. The impact on mosquito populations has also been reported more qualitatively. Roughly half of the studies report simultaneous increases and decreases in different species, directly altering mosquito assemblage. In addition, the dominant species often changes after a flooding event, frequently shifting towards floodwater species [21, 30, 55]. These results highlight how species-specific effects can disrupt the overall ecology of flooded areas and should be considered beyond a single-species approach [15].

The effect of flooding also depends on several environmental factors, notably rainfall, temperature, standing water, and humidity, all of which are well known to influence mosquito development [6]. The vast majority of studies report that rainfall plays an important role in determining how mosquito populations change after a flood. For example, Mathur et al. [35] assign a pioneering role to rainfall after years of drought, which made the effects of the subsequent flooding possible. While Berec et al. [7] consider rainfall to modulate the effect, Hajkova et al. [22] and Neville et al. [43] find that rainfall prolongs inundation with a subsequent effect on mosquito population. In addition to that, temperature is known to determine the time required for mosquitoes to develop [6]. For example, Kuroli et al. [30] reported high temperatures, including in standing water, which facilitate rapid development of mosquitoes while the area is still flooded. Berec et al. [7] go further in analyzing the relation between mosquito population, temperature and flooding, concluding that flooding determines the timing of the seasonal peak, while temperature modulates it. Flooding also affects standing water and humidity, thereby directly interfering with mosquito development [37]. Although urbanization was mentioned in a limited number of the studies, it has been shown to have a relevant effect: it defines the habitat and therefore determines the species present and the possible effects of flooding, including the destruction of human-made structures such as buildings, the creation of breeding containers, and the flooding of existing breeding containers [5, 42]. MacDonald et al. [34], for example, found an effect of flooding only on the more rural *Cx. tarsalis*, but not on the urban container-breeding species *Ae. aegypti* or *Cx. quinquefasciatus*. A prominent role is also played by the properties of the flood, particularly the flood level and flood duration. In particular, the flood duration must not be too short in order to allow mosquito development [30, 55]. This is often related to the persistence of flooded area because of rainfall, poor drainage networks or soil types [43]. Mourelatos et al. [41] and Sebesta et al. [55] further provide clear examples of the importance of flood timing in temperate regions, as flooding affects mosquito populations only during the appropriate seasons or under suitable conditions.

Indeed, our systematic review highlighted that the effects of flooding vary from species to species. At a broader level of aggregation, several studies group mosquito species into non-floodwater mosquitoes, e.g. *Ae. aegypti*, and floodwater mosquitoes. Vigilant et al. [51] find permanent-water mosquitoes to be reduced after flooding, in contrast to floodwater species, which were found to increase. Khan et al. [28] adopt a similar grouping approach and conclude that flooding has a positive effect on species from the Mansonia genus, while it can decrease other species. In contrast, several studies also report increases in non-floodwater species after floods. For example, Barrera et al. [5] found that *Ae. aegypti* increased in areas without vector control, Barrera et al. [25] revealed a sharp increase in *Culex quinquefasciatus*, and Weaver et al. [53] reported increases in *Ae. aegypti*, *Ae. albopictus*, and *Cx. quinquefasciatus*. These findings are again contrasted by MacDonald et al. [34], who found no impact on the populations of *Cx quinquefasciatus* and *Ae. aegypti*. In particular, increases in *Ae. aegypti*, *Cx. quinquefasciatus*, and *Ae. albopictus* appear to have been observed after hurricanes [5, 25, 53]. This raises the question of whether hurricane-related damage, in addition to flooding, has a significant effect on increasing permanent-water mosquitoes. A potential explanation could be that hurricanes may additionally damage infrastructure, thereby creating artificial breeding containers.

The observed effects on mosquito populations may also be due to the trap types used. For Europe, Lühken et al. [33] found that BG traps collected the greatest number of mosquito species, particularly species of the *Culex* genus and*Aedes/Ochleratus* species. Furthermore, *Ae. vexans* was most effectively collected using CDC light traps, which were also identified as the most suitable option in floodplains. In contrast, BG traps were most suitable for urban environments [33]. This is consistent with, for example, Moise et al. [37], where BG traps identified *Cx quinquefasciatus* as one of three dominant species after Hurricane Irma, whereas CDC light traps identified seven different dominant species, including *Ae. tortilis* and *Psorophora columbia*. Similarly, Weaver et al. [53] collected different species using different traps and reported corresponding differences in changes in species-specific mosquito counts. Thus, caution should be exercised when comparing effects on floods on different species when considering only one trap type.

Having established that the effects of flooding on mosquito populations represent a relatively recent and still developing research area, several recommendations for future studies can be formulated, with particular attention to the data requirements and methodological approaches.

- **Geographic coverage:** Studies spanning a wider range of geographic regions would improve understanding of flood-mosquito dynamics across diverse ecological and climatic contexts, including regions projected to face increasing flood risk. Specifically, studies for South America and Southeast Asia have not been found, and limited coverage of Africa has been observed. Broader geographic coverage would also better reflect the regional variation in mosquito species composition. Furthermore, both urban and rural settings should be considered to explore the impact of different levels of urbanization.
- **Temporal resolution:** Although challenging to achieve in practice, mosquito population data should ideally be collected over multiple years both before and after a flood event, in order to establish robust baselines against which post-flood counts can be compared. Within the flood period itself, continuous trapping at the highest feasible frequency over several weeks would allow the different phases of the population response to be captured and distinguished.
- **Spatial resolution:** Analogous considerations apply to spatial coverage. Deploying traps across a spatial distribution that adequately represents the study area, rather than at a single location, would improve the representativeness of the data. This distribution should, where possible, extend beyond the immediately flooded zone, as at least one included study reported population effects at distances of approximately 5 to 15 km from the flood boundary [34].
- **Trap selection and combination:** Where logistically feasible, combining multiple trap types or selecting the trap type most appropriate to the target species would further improve data quality and comparability across studies.
- **Environmental factors and flood properties:** Standardized reporting of environmental variables known to influence mosquito populations, both

in general and in the context of flooding specifically, would be highly desirable. Consistent documentation of such factors would facilitate cross-study comparisons and support a more rapid understanding of the drivers of variability in flood responses.

- **Statistical and analytical rigor:** Approximately half of the included studies statistically tested their results, and at least one study showed that, depending on the method applied, substantially different conclusions could be drawn [25]. Rigorous statistical analyses are therefore necessary to generate robust and reproducible findings.

- **Data availability:** Researchers who make their raw data openly and readily accessible, alongside transparent reporting of any additional datasets used, provide considerable value to the broader scientific community. Publicly available data can be reanalysed using alternative methods, incorporated into meta-analyses, or used to parameterize and validate modeling studies.

Our systematic review comes with several limitations, that we discuss in what follows. First, we must acknowledge that the selected studies were highly heterogeneous in design, collection protocol and analysis methods. Therefore, aggregation and harmonization were performed as far as possible, but the conclusions drawn should not be over interpreted. Additionally, we restricted our search to the impact of floods with a very long return period, which could be loosely defined as rare and extreme, with the aim of focusing on situations that involved a major shock of the ecological system. We therefore excluded artificial and regular floods, which may have provided further insight. For example a study from Hesson et al. [23] found a correlation between river discharge and mosquito populations but did not meet the scope of this review. Future research is therefore encouraged to consider different flood settings. Finally, three databases, namely Embase, Scopus, and PubMed, were searched, and only articles published in English were accepted. Therefore, additional relevant research may exist, although the databases searched should cover the most relevant literature. In conclusion, our findings highlighted the complex interplay of mosquitoes and flooding events; while it is clear that floods substantially affect mosquito abundance, species composition and assemblage, no simple or universally applicable conclusion can be drawn. The direction and magnitude of the response depend on the mosquito species, environmental conditions, flood properties, habitat characteristics, vector control measures, trapping methods, and the temporal and spatial resolution of the study. Flooding may therefore increase some species while decreasing others, and these responses may also change over time. These findings highlight the need for more geographically diverse, standardized, and high-resolution studies with appropriate statistical analyses and also highlight the potential value of modeling for quantifying the contribution of each effect.

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