Effectiveness of disinsection of conveyances to prevent or reduce the spread of mosquito vectors via international travel

Evidence reviews

World Health Organization

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Foreword

Treatment of aircraft with insecticide in a procedure referred to as “disinsection” is recommended to prevent dispersal of arthropod vectors internationally and to mitigate the globalization of vector-borne infectious diseases. However, the full spectrum of vector- and human-based outcomes, along with standard decisional considerations of aircraft disinsection, have not been recently synthesized. Moreover, there is a paucity of synthesized information regarding the efficacy, safety and general utility of marine, rail and land conveyance disinsection.

Using an evidence-based knowledge synthesis approach, we examined the effectiveness of disinsection for eradicating adult mosquitoes aboard international air, marine and land conveyances, and additionally investigated the human safety, toxicity and tolerability of insecticides applied for the purpose of mosquito disinsection. We further synthesized the surveillance literature of mosquitoes aboard aircraft, ships, trains and buses and in proximity to international conveyances at points of entry, submarine bases and spacecraft stations in order to understand the potential for importation of mosquito vectors of pathogens and subsequent transmission of mosquito-borne infectious diseases in the receiving country (that is, the country of arrival).

Credit: WHO
Dengue Control and Prevention Campaign, March 2024

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Declaration of interest

All external contributors completed a WHO declaration of interests form in accordance with WHO policy for experts. The declarations of interest and the results of a web-based search for each member were reviewed by WHO staff. No conflict of interest was declared by any of the external expert review group members.

Credit: WHO / Ahmad Yusni
Public health assistant set sticky traps to capture adult Aedes mosquitoes for surveillance and control of dengue in Selangor.

Abbreviations

CANDALS	citizenship; ability; neurotypicality or neurodiversity; disability; age; literacy and/or fluency in a universal language of aviation; and size, body mass index (BMI) or body habitus
CI	confidence interval
DDA	dichlorodiphenylacetic acid
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
GRADE	Grading of Recommendations Assessment, Development and Evaluation
ICAO	International Civil Aviation Organization
IHR	International Health Regulations
PICO	Population, Intervention, Comparator, Outcome
PRISMA	preferred reporting items for systematic reviews and meta-analyses
PROGRESS	place of residence, race/ethnicity, occupation, gender/sex, religion, education, socioeconomic status and social capital
SRA	standard reference aerosol
WHO	World Health Organization

Credit: WHO / David Spitz
Zika prevention event in Colombia

Executive summary

Background. Treatment of aircraft with insecticide in a procedure referred to as "disinsection" is recommended to prevent dispersal of arthropod vectors internationally and to mitigate the globalization of vector-borne infectious diseases. However, the full spectrum of vector- and human-based outcomes, along with standard decisional considerations of aircraft disinsection, have not been recently synthesized. Moreover, there is a paucity of synthesized information regarding the efficacy, safety and general utility of marine, rail and land conveyance disinsection.

Methods. Using an evidence-based knowledge synthesis approach, we examined the effectiveness of disinsection for eradicating adult mosquitoes aboard international air, marine and land conveyances, and additionally investigated the human safety, toxicity and tolerability of insecticides applied for the purpose of mosquito disinsection. We further synthesized the surveillance literature of mosquitoes aboard aircraft, ships, trains and buses and in proximity to international conveyances at points of entry, submarine bases and spacecraft stations in order to understand the potential for importation of mosquito vectors of pathogens and subsequent transmission of mosquito-borne infectious diseases in the receiving country (that is, the country of arrival). A bipartite systematic review was commissioned to evaluate evidence, with the search strategy capturing literature from inception up to 31 May 2024. The systematic review was conducted according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines and was registered in the International Prospective Register of Systematic Reviews, PROSPERO (CRD42024543998).The certainty of the evidence was rated and key primary outcomes, including mosquito mortality and human health effects of conveyance disinsection, were synthesized along with epidemiological mosquito surveillance data.

Results. A total of 107 main studies or reports fulfilled inclusion criteria, including 19 that were experimental trials of disinsection reporting the outcome of mosquito mortality; nine that were conducted with an unexposed arm of comparator mosquitoes; 21 that described human health effects of conveyance disinsection and reported outcomes of safety, toxicity and tolerability; 52 surveillance reports of mosquitoes detected aboard conveyances; and 28 surveillance reports of mosquitoes detected at international points of entry, including five reports of airport or airplane malaria, where the mechanism of transmission was convincingly causally related to airport or airplane exposure. Studies reporting the main primary outcomes of mosquito mortality and human health effects were of generally poor quality and had high risk of bias, with low to very low certainty of estimates of effect. Adherence to the World Health Organization (WHO) published guidelines for studies evaluating the efficacy of aircraft disinsection was 33.3%, ranging from 18.2% to 60.5%. No high-quality studies investigating the human safety, toxicity or tolerability of disinsection were identified. Rather, the literature base describing human health effects of disinsection comprises very limited post hoc public health surveillance, small cohort studies, one case–control study, case series and case reports. Collectively across comparator trials of aircraft disinsection efficacy, the odds of mosquito mortality in the experimental (exposed) arms compared to control (unexposed) arms (that is, the odds ratio) was 163.6 (95% confidence interval (CI), 147–182) and the risk of mosquito death in the exposed versus unexposed arms (that is, the relative risk) was 14.24 (95% CI, 12.99–15.63). The directionality of effect estimates was consistent across subgroups analysed for efficacy of disinsection, including mosquito species, method of disinsection, type of aircraft and specific insecticide used; however, the size of effect estimates varied, often by orders of magnitude. The only WHO-recommended insecticide formulation to be tested in a mosquito-controlled comparator trial was 2% d-phenothrin aerosol, which yielded significant odds of mosquito mortality for disinsection versus control of 171.7 (95% CI, 139.1–212) across four studies with relative risk of 20.08 (95% CI, 16.53–

24.43). Human health effects including morbidity leading to workdays lost or adverse events including hospitalization, objective measures of insecticide toxicity including detectable and elevated serum or urinary metabolites, and subjective reporting of symptoms consistent with acute insecticide poisoning were reported by the small number of uncontrolled observational studies and public health surveillance reports included. Of particular note was a cohort study of flight attendants in whom urinary concentrations of pyrethroids in those flying disinsected routes far exceeded those of unexposed flight attendants and the general population, with metabolite elevations proportionate to duration of exposure, meaning that longer flights conferred greater probability of detectable insecticide metabolites. How these elevated levels of insecticide metabolites in the context of occupational exposure impact health is unknown. Additional outcomes reported by studies fulfilling inclusion were user acceptability; feasibility of disinsection; operational efficiencies; public health and health system considerations; impacts of insecticide on conveyance integrity; financial impacts; legal considerations; political or sociocultural considerations; carriage of pathogens by mosquitoes identified; and presence of insecticide resistance. No included studies reported on impacts on the environment or health equity and human rights considerations. Surveillance of air, marine and land conveyances and their proximities, at points of entry, identified vector-competent adult mosquitoes of clinically important species across the *Aedes*, *Anopheles*, *Culex* and other genera. Notable detection of particularly relevant species, such as *Aedes aegypti* aboard aircraft and *Ae. albopictus* at points of entry where these species are non-endemic – such as in Belgium, Germany, Japan and the United Kingdom of Great Britain and Northern Ireland (the United Kingdom) – underscore the potential for vector dispersal globally. Moreover, the novel detection of *Ae. albopictus* and Ae. japonicus aboard ships porting in New Zealand underscores the potential for conveyance of exotic mosquito species via marine routes. Only four reports assayed detected mosquitoes for pathogen carriage such as flaviviruses and chikungunya virus, and in only one report was West Nile virus detected among mosquitoes surveyed at a Naval submarine base in the United States of America (the United States). Included cases of airport and airplane malaria were convincingly linked to human exposures to infective mosquitoes in aircraft cabins, cargo holds, luggage containers (LD3 or LD2) for baggage storage on aircraft, baggage handling areas and via airmail, while two reports of mosquitoes aboard spacecraft highlight the insect's ability to access human-created environments from which its exclusion – for reasons of health, safety and potential dissemination – should be absolutely assured.

Conclusions. The systematic review identified only four mosquito-controlled comparator trials investigating the efficacy of a WHO-recommended insecticide formulation (2% dphenothrin) for the purpose of aircraft disinsection, which supported a high degree of insecticidal efficacy. Studies on 2% permethrin or 2% 1R-trans-phenothrin were not identified. Furthermore, no studies (of 19 included) of any insecticide identified by the systematic review adhered to WHO recommendations for conduct of such experimental trials, and as such the true efficacy of such disinsection procedures in a real-life context is uncertain. Moreover, reports of health equity and human rights considerations of disinsection were absent from the included literature. Of particular concern is the breadth and quality of evidence surrounding human health impacts, as no high-quality studies investigating the safety, toxicity or tolerability of disinsection were identified. Experimental trials that did comment on safety and tolerability in humans were primarily designed to test insecticidal efficacy of disinsection, and standard human subject considerations and measures of methodological rigour in clinical research were largely ignored or not reported. The one highest-quality cohort study of flight attendants noted demonstrable elevations of urinary pyrethroid metabolites in those flying disinsected routes; however, the human health impact of such metabolite detection is unknown. This scant literature base has a high risk of bias; however, given the reports of significant morbidity, adverse events and toxicity putatively attributable to aircraft disinsection, well designed clinical trials investigating the full range of human health impacts of disinsection on passengers and crew are urgently needed. The rationale for surveillance of aircraft and marine vessels, and their respective points of entry, for adult mosquitoes was amply supported by the synthesized literature. Such surveillance should be expanded to include systematic screening of surveilled mosquitoes for pathogen carriage, and efforts to understand the role of conveyance disinsection in the prevention and mitigation of novel introductions of vector-competent mosquitoes to non-endemic areas should be undertaken.

Credit: WHO / Yoshi Shimizu
A community health worker conducts a field sampling of mosquitoes.

Credit: WHO / Ahmad Yusni
Health official inspects a rat trap on a vessel in Port Klang, Selangor.

1. Background and rationale

1.1 Work of the World Health Organization (WHO) on disinsection

Aircraft may introduce insect vectors of infectious disease agents to locations in which they were not previously present *(1)*. In addition, insects (vectors) may transmit pathogens to people in places served by aircraft (giving rise to "airport malaria"). Mosquitoes act as vectors of pathogens that cause a number of serious diseases, including malaria, dengue, chikungunya, Zika virus disease and yellow fever.

WHO's previous formal publication on aircraft disinsection was published in 1995 in the International Programme of Chemical Safety series *(2)*. In 2000, the importance of disinsection of aircraft departing from airports in disease-endemic areas into non-endemic areas was discussed *(3)*. The International Health Regulations (IHR) (2005) *(4)*, which were adopted by the World Health Assembly in 2005 and came into force in 2007, establish global benchmark standards to prevent, protect against and control insect-borne diseases, and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks and that avoid unnecessary interference with international traffic and trade. As set out in the IHR, "every conveyance leaving a point of entry situated in an area where vector control is recommended should be disinsected and kept free of vectors. When there are methods and materials advised by the Organization for these procedures, these should be employed" (IHR, Annex 5). States Parties shall establish programmes to control vectors that may transport an infectious agent that constitutes a public health risk to a minimum distance of 400 metres from those areas of point of entry facilities that are used for operations involving travellers, conveyances, containers, cargo and postal parcels, with extension of the minimum distance if vectors with a greater range are present (IHR, Annex 5.4) *(4)*. States Parties may subject the granting of free pratique to inspection and, if a source of infection or contamination is found on board, the carrying out of necessary disinfection, decontamination, disinsection or deratting, or other measures necessary to prevent the spread of the infection or contamination (IHR, Article 28.2). A list of countries with specific aircraft disinsection regulations can be found in Annex 1 to the present document.

The IHR (2005) define disinsection as:

> the procedure whereby health measures are taken to control or kill the insect vectors of human disease present in baggage, cargo, containers, conveyances, goods and postal parcels (IHR, Part I, Article 1),

and state that it should "be carried out so as to avoid injury and, as far as possible, discomfort to persons …" (IHR, Part IV, Article 22, section 3) *(4).*

The International Civil Aviation Organization (ICAO), which harmonizes standards in civil aviation, including aircraft and at airports, encourages Member States to complete the Airport Vector Control Register maintained by ICAO and emphasizes the importance of guidelines on vector surveillance and control in airports *(5)*. Similarly, in the marine sector, "the presence of vectors on board conveyances and the control methods used to eradicate them shall be included on the Ship Sanitation Control Certificate" (IHR, Part IV, Articles 22 and 24, and Annexes 3, 4 and 5) *(6)*.

In 2016, WHO convened an expert group in response to the spread of Zika virus disease, which considered that disinsection would have little effect in preventing importation of the virus, as it is imported mainly by infected travellers and, to a lesser extent, by mosquito vectors *(7)*. ”Some cases have been identified of dengue viruses carried by mosquitoes in aircraft. Even if the risk is very low, it nevertheless remains, and WHO considered it important to address the issue” *(1)*.

A WHO consultation in 2018 recognized that guidance on aircraft disinsection methods and procedures was required, with standard operating procedures for aircraft disinsection and training materials and tools *(8)*. The first edition of the *WHO aircraft disinsection methods and procedures* was published in 2021 to address the first requirement *(9)*. The 2023 update of that document *(1)*, based on the feedback received from various stakeholders, provides updates on methods of insecticide delivery and associated equipment (see Annex 2 to the present document), aerosol and residual sprays specifications, updated tables for calculating amounts of aerosol spray required, updated protocols for pre-embarkation and pre-departure cabin treatment, and the ICAO certification requirements.

1.2 Examples of geographical spread of major mosquito-borne diseases

As discussed above, for some vector-borne diseases, import is mainly by infected travellers and, to a lesser extent, by mosquito vectors. With that caveat in mind, we have summarized some examples of geographical spread of major mosquito-borne diseases below.

1.2.1 Dengue

The global incidence of dengue has increased markedly over the past two decades, posing a substantial public health challenge *(10)*. From 2000 to 2019, WHO documented a tenfold surge in reported dengue cases worldwide, increasing from 500 000 to 5.2 million per year. The year 2019 marked an unprecedented peak in dengue cases, with reported incidences spread across 129 countries.

After a slight decline of cases between the years 2020 and 2022 due to the COVID-19 pandemic and lower reporting rate, in 2023, an upsurge in dengue cases was observed globally, characterized by a significant increase in the number, scale and simultaneous occurrence of multiple outbreaks, spreading into regions previously unaffected by dengue. Around 5 million cases were reported globally and more than 5000 dengue-related deaths occurred in over 80 countries and territories and five WHO regions: the African Region, the Region of the Americas, the South-East Asia Region, the Eastern Mediterranean Region and the Western Pacific Region.

As of 23 December 2023, close to 80% of these cases, or 4.1 million, have been reported in the Region of the Americas alone. Dengue is the most widespread arbovirus that causes the highest number of arboviral disease cases in the Region of the Americas, with cyclic epidemics recurring every three to five years. In addition, clusters of autochthonous dengue have been reported in the WHO European Region since 2010. However, these numbers are probably an underestimate of the true burden, as most of the primary infections are asymptomatic and dengue reporting is not mandatory in many countries.

Several factors are associated with the increasing risk of spread of the dengue epidemic, including the changing distribution of the vectors (mainly *Ae. aegypti* and *Ae. albopictus*), especially in previously dengue naïve countries; the changing pattern of the four circulating serotypes (DENV-1 to DENV-4); urbanization; the consequences of El Niño phenomena in 2023 and climate change leading to increasing temperatures, high rainfall and increased humidity, among other effects; fragile health systems in the midst of the COVID-19 pandemic; political and financial instability in countries facing complex humanitarian crises with high population movements; and associated water storage practices in containers suitable for *Aedes* spp. immature habitation and growth. Dispersal of mosquito eggs via transportation of used tyres and ornamental plants is a particular concern. Collectively, these factors also challenge the response to the epidemic and the risk of further spread to other countries. Weakness in the surveillance systems in many affected countries may have led to delayed reporting and response and missed identification of symptoms, contributing to increased severe dengue outcomes.

1.2.2 Chikungunya

Chikungunya virus was first identified in the United Republic of Tanzania in 1952 and subsequently in other countries in Africa and Asia *(11)*. Urban chikungunya virus disease outbreaks were first recorded in Thailand in 1967 and in India in the 1970s. Since 2004, outbreaks of chikungunya have become more frequent and widespread, partly caused by viral adaptations allowing the virus to be spread more easily by *Ae. albopictus* mosquitoes. The disease causes very painful conditions of myalgia and arthralgia of short or long duration and is responsible for enormous disability. Chikungunya has now been identified in over 110 countries in Asia, Africa, Europe and the Americas. Transmission has been interrupted on islands where a high proportion of the population has been infected and has now become immune; however, transmission often persists in countries where large parts of the population have not yet been infected. All regions with established populations of *Ae. aegypti* or *Ae. albopictus* mosquitoes have now experienced local mosquito-borne disease transmission.

1.2.3 Western equine encephalitis

Since November 2023, a sustained increase in cases of Western equine encephalitis in equines and humans has been observed in both Argentina and Uruguay *(12)*. In addition, a case of Western equine encephalitis was detected in an equine in Brazil, in the state of Rio Grande do Sul, which shares its southern border with Uruguay and its western border with Argentina. According to information available from official sources, 2464 outbreaks in animals (1445 in 16 provinces of Argentina, 1018 in 16 departments of Uruguay, and one case in a Brazilian state) and 73 confirmed cases in humans (69 in Argentina and four in Uruguay) have been reported. The distribution of confirmed human cases in Argentina and Uruguay coincides with areas with a high number of suspected and confirmed equine cases. In Argentina, seven human deaths resulting from Western equine encephalitis have been confirmed *(12)*.

1.2.4 Zika virus disease

From the 1960s to 1980s, sporadic human infections of Zika virus were detected across Africa and Asia *(13–15)*. However, since 2007 outbreaks of Zika virus disease have been recorded in Africa, the Americas, Asia and the Pacific. A large outbreak of Zika virus disease was reported in 2015–2016 in Brazil. On 1 February 2016, WHO declared that the association of Zika infection with clusters of microcephaly and other neurological disorders constitutes a public health emergency of international concern *(16)*. Cases of Zika virus disease globally declined from 2017 onwards; however, Zika virus transmission persists at low levels in several countries in the Americas and in other endemic regions. In addition, the first local mosquito-transmitted Zika virus disease cases were reported in Europe in 2019, and Zika virus outbreak activity was detected in India in 2021, 2023 and 2024. To date, a total of 89 countries and territories have reported evidence of mosquito-transmitted Zika virus infection; however, surveillance remains limited globally.

1.2.5 Malaria

There is also concern on the importation of malaria vectors from their native endemic areas to new geographical areas *(17)*. *Anopheles stephensi* is a mosquito species that is capable of transmitting both *Plasmodium falciparum* and *P. vivax* malaria parasites. It was originally native to South Asia and parts of the Arabian Peninsula but has been expanding its geographical range over the last decade, with detections reported in Djibouti (2012), Ethiopia and Sudan (2016), Somalia (2019), Nigeria (2020) and Ghana, Eritrea and Kenya (2022). To date, it remains unclear when and via which route these countries were invaded. However, transport by conveyances of infected persons or adult *An. stephensi* vectors is a possibility, as is the phenomenon of “airport malaria”.

1.3 Rationale

Vehicular conveyances, encompassing marine, rail, ground and aircraft transportation, contribute to the global spread of infectious diseases, including malaria, dengue, chikungunya and Zika, via movement of infected people as well as through transmission-capable adult vectors. Consequently, vehicular disinsection using aerosol or residual sprays of chemical (insecticidal) products has been indiscriminately utilized to eliminate relevant vectors, including mosquitoes. The increase and geographical spread of mosquito-borne infections in recent years, as explained above, has drawn renewed attention to the effectiveness of disinsection of aircraft. However, since the evidence review of the effectiveness of disinsection of aircraft was last published in 2020 with the cut-off date of 31 December 2018 *(18)*, it is urgent to update the evidence review and inform the decision-making process of Member States and travel and transport industries alike under the current situation of intense dengue transmission and the spread of invasive mosquito vector species.

As such, there is a risk of introduction of vectors, including disease agents, to locations in which they were not previously present by modes of transport other than aviation, including land and water (for example by sea, lake or river). A list of countries with specific marine conveyance disinsection regulations can be found in Annex 3.

As an evidence review for non-aviation modes of transport has never been done, WHO decided to include those modes of transport in the scope of the present review. For the purposes of this systematic review, in addition to the IHR definition of “point of entry” (see Article 1), we also aimed to capture areas in proximity to points of entry beyond a range of 400 metres (Annex 5.4), as well as submarine bases and spacecraft stations. Throughout this document, “points of entry” include all such aforementioned locales.

2. Methods

2.1 Process

Though this is not a guideline development work, the process described in the *WHO handbook for guideline development (19)* was followed for quality control. An external experts group is a group of experts selected in their personal capacity following WHO rules and protocols to ensure their independence and impartiality when assessing systematic review findings and drawing conclusions. When establishing the External Experts Group for review of evidence of the effectiveness of disinsection of conveyances, WHO selected members to ensure a global geographical representation, gender balance, and appropriate technical and clinical expertise.

The Steering Group for the review comprised WHO and relevant United Nations staff with expertise in the technical areas of infectious diseases, vector control, aircraft disinsection, chemical safety, IHR, health systems, international travel and border health, international migration, and occupational health, as well as WHO regional office representatives. The Steering Group members developed the draft Population, Intervention, Comparator, Outcome (PICO) research question and helped to identify appropriate External Review Group members, who provided feedback for the Steering Group and External Experts Group to consider. The Steering Group, External Experts Group and External Review Group were consulted to make final decisions on research questions and then, once the systematic review was completed and draft evidence review written, were further consulted to review the synthesized evidence findings, including the Grading of Recommendations Assessment, Development and Evaluation (GRADE) summary of findings tables and full text provided by the systematic review team. The work started in May 2024 and concluded in September 2024.

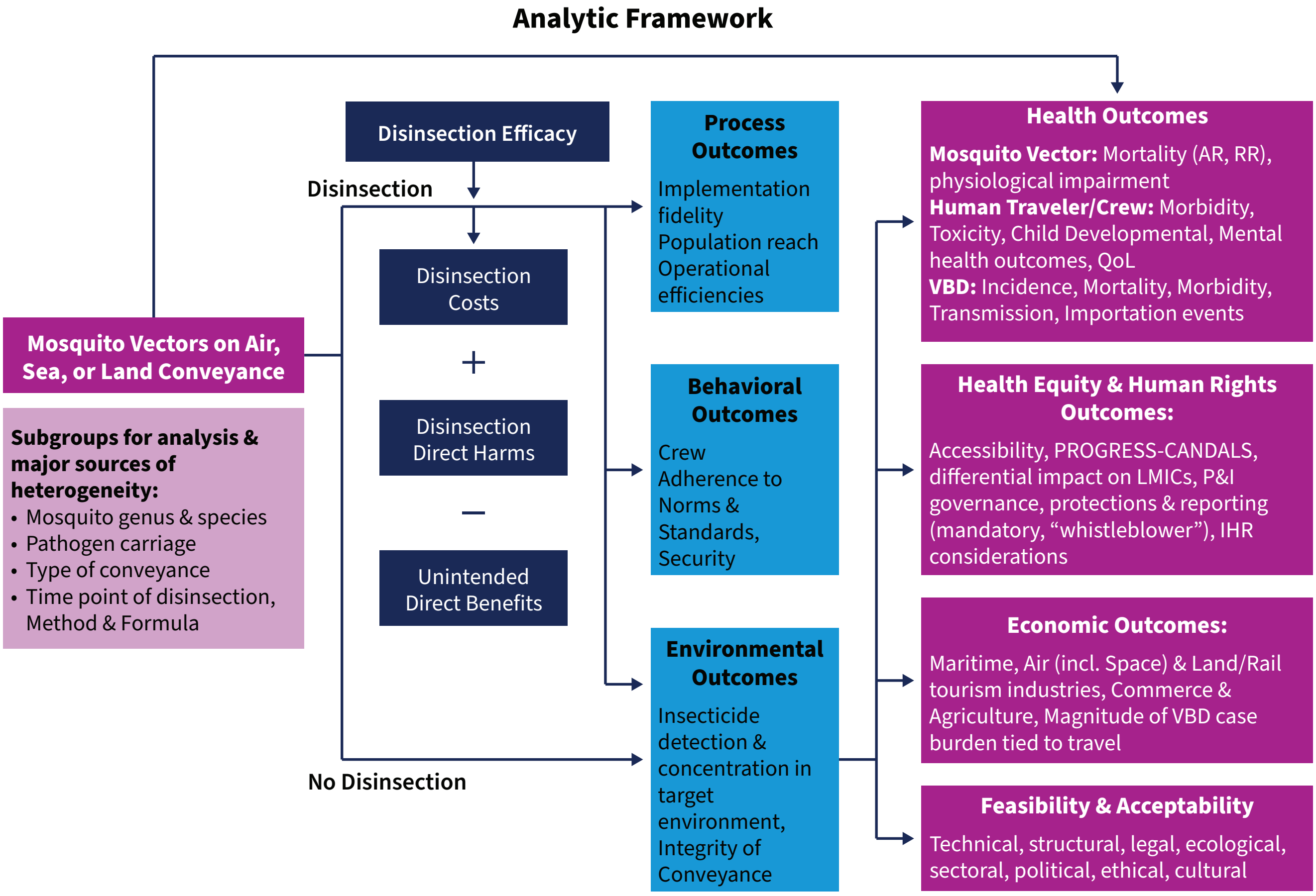
Credit: WHO
Surveillance of dengue vectors in Baghdad and Erbil - June 2021

2.2 Establishing the research question

Two systematic reviews were conducted in accordance with the analytic framework outlined in Figure 1.

Figure 1. Analytic framework mapping the population of interest to intermediate and ultimate outcomes.

(Abbreviations: AR, absolute risk; LMICs, low- and middle-income countries; P&I, privacy and information; QoL, quality of life; RR, relative risk; VBD, vector-borne disease.)



The first part of the systematic review synthesizes the effectiveness of disinsection of international travel carriers (passenger chamber, cargo area, cargoes, air-cans) of all modes of transportation (air, water, and land transport) to prevent or reduce the spread of mosquito vectors via international travel (Table 1).

Table 1. PICO for the effectiveness of disinsection

Question: What is the effectiveness of disinsection of international travel carriers versus no disinsection (passenger chamber, cargo area, cargoes, air-cans or containers) of all modes of transportation (air, water, and land transport) to prevent or reduce the spread of mosquito vectors via international travel?	
Population	Mosquitoes (by species)
Intervention	Disinsection of international travel carriers (passenger chamber, cargo area, cargoes, air-cans or containers) of all modes of transportation (air, water, and land transport), by chemical *(20)* or non-chemical agent, method used, and other

Comparator	No disinsection of international travel carriers (passenger chamber, cargo area, cargoes, air-cans or containers) of all modes of transportation (air, water, and land transport)
Outcome	1. No or reduced number of mosquitoes on aircraft (passenger chamber, flight deck, cargo area, air-cans or containers) or cargoes (water, land transport); 2. Unintended consequences: (a) to individual health (travellers and staff); (b) additional financial cost incurred by travellers and aircraft (passenger chamber, cargo area, air-cans or containers), cargoes (water, land transport vehicles); (c) to health equity and human rights, with special attention to children and people with chronic conditions such as asthma and according to the PROGRESS-CANDALS framework;[1] (d) operational constraints (such as additional time required, safe disposal of empty containers, procurement difficulties); (e) security or safety (incidents such as explosion resulting from inappropriate application of disinsection agents); (f) effects on critical components of conveyance equipment, such as aircraft components, plastics in oxygen masks, cabin walls, electrical components; (g) effects of insecticides on the environment (water, food, soil, waste management and other); (h) insecticide resistance. 3. Decisional factors with quantitative or qualitative outputs: (a) fiscal, including economic costs of implementation; (b) feasibility; (c) user acceptability (both passengers and staff); (d) public health and health care systems and port authority (minimum requirements in terms of infrastructure, logistics and human resources, predictable seasonal surge capacity, and unforeseeable ad hoc emergency surge capacity); (e) sociocultural or political (such as bilateral agreements, United Nations agencies, unions); (f) legal (for example, documented and undocumented, IHR requirements, bilateral, multilateral or interagency joint statements); (g) Status of mosquito susceptibility to the proposed insecticides.

1 See section 2.5 below.

The second part of the systematic review reports empirical studies on reports of (a) mosquitoes carried by and (b) pathogens carried by mosquitoes by international travel carriers (passenger and crew cabin, cargo hold, cargoes, air-cans) of all modes of transportation (air, water, and land transport) (Table 2).

Table 2. Systematic review of empirical studies on mosquitoes carried by international travel

No.	Question
Review question (a)	What is the evidence of mosquitoes (including invasive species) carried by international travel carriers (passenger chamber, cargo area, cargoes, air-cans or containers) of all modes of transportation (air, water, and land transport)?
Review question (b)	What is the evidence of mosquitoes carrying a vector-borne disease pathogen by international travel carriers (passenger chamber, cargo area, cargoes, air-cans or containers) of all modes of transportation (air, water, and land transport)?

2.3 Conducting the systematic review

A two-part systematic review was commissioned according to the PICO framework outlined above. The systematic review was conducted according to the preferred reporting items for systematic reviews and meta-analyses (PRISMA) guidelines *(21)* and was registered in the International Prospective Register of Systematic Reviews, PROSPERO (CRD42024543998).

Inclusion criteria. We included all papers relating to disinsection of international travel carriers (passenger chamber, cargo area, cargoes, air-cans) of all modes of transportation (air, water, and land transport) by chemical agent (including DDT, d-phenothrin, 1R-trans-phenothrin, and permethrin), disinsection method used (aerosol types and residual), and targeting mosquitoes. Systematic reviews, randomized controlled trials (RCTs), cohort studies, cross-sectional studies, case–control studies, case series, and case reports (n ≥ 1) were all included. Studies with alternative methodological designs but reporting primary data (such as conference presentations) were also included. We additionally included all studies reporting on the identification of mosquitoes on or in a conveyance or at international points of entry, regardless of the application of a disinsection process, in order to fulfil the objectives of the second systematic review. For the purposes of this systematic review, “points of entry” includes all crossings captured by the IHR (Article 1), as well as any bases at which conveyances could be stationed, and areas in proximity to points of entry beyond 400 metres (IHR, Annex 5.4).

Exclusion criteria. We excluded studies reporting only in vitro data, animal studies, and those that did not permit assessment of any predetermined outcomes of interest (such as mathematical modelling studies). We further excluded studies conducted in putative models of conveyances that did not fully replicate the conveyance environment (such as non-pressurized shed as a model of an aircraft cabin, or pieces of carpet treated with insecticide in a laboratory as a model of residual disinsection). We additionally excluded epidemiological studies of airport malaria where the mechanism of transmission was not unequivocally aircraft or airport related, and we further excluded epidemiological studies reporting only on larval surveillance activities as a proxy for vector-competent adult mosquitoes.

Outcomes. Outcomes of interest are as described above for the PICO framework (Tables 1 and 2). The four primary outcomes addressed and leading to generation of the summary of findings tables are:

- efficacy of disinsection, with the outcomes of relative and absolute mosquito mortality;

- Human safety and toxicity of disinsection, with the outcomes of proportionate and absolute human adverse events, biological toxicity, measures of tolerability, morbidity and mortality;
- identification through surveillance activities of vector-competent adult mosquitoes aboard any conveyance or its cargo, with the outcome of absolute abundance;
- identification through surveillance activities of vector-competent adult mosquitoes at points of entry, including airports, seaports ("ports" in the IHR), railways, stations and international motorways ("ground crossings" in the IHR), with the outcome of absolute abundance.

2.4 Searches

Six electronic databases (PubMed, EMBASE, MEDLINE, Scopus, LILACS, CINAHL) were searched from inception to 31 May 2024 without language restriction using the following search terms:

(disinsection OR insecticide OR d-phenothrin OR permethrin OR deet OR spraying OR "mosquito control") AND (travel OR airport OR airplane OR plane OR aviation OR aircraft OR airline OR air-cans OR truck OR bus OR cargo OR rail OR train OR tram OR marine OR ship OR boat OR lorry OR vessel OR submarine OR space OR spacecraft OR rocketship OR spaceship OR "marine vehicle" OR "marine vessel" OR "cruise ship" OR "water taxi" OR ferry OR barge OR "passenger chamber" OR "cargo area" OR "land transport vehicles") AND (neurotoxicity OR crew OR passengers OR "flight attendant" OR "occupational exposure" OR insect OR mosquito OR malaria OR "airport malaria" OR dengue OR chikungunya OR zika).

OpenGrey and the Grey Literature Report databases were also searched for additional literature, including conference proceedings, dissertations and other documents. Bibliographies of key papers were also hand-searched for relevant literature not captured by the above search strategy. Following de-duplication, the strategy identified a total of 8610 unique studies, which underwent double-screening by two authors at the title and abstract stage (see Figure 2 below). After title and abstract screening, 505 unique papers were identified for full-text screening. Following double-review by two authors, 398 full texts were excluded for reasons indicated in the PRISMA flow diagram (Figure 2), and 107 were included for data extraction and synthesis.

Document organization and de-duplication, as well as title, abstract and full-text screening, were executed using the online platform Covidence. Articles were independently double-screened by two reviewers and any discrepancies were resolved through discussion or, in the event of non-agreement, by a tertiary arbitrator.

Data extraction was conducted by two independent reviewers and verified and collated by the study lead according to the GRADE framework *(22–24)*. Non-English articles were screened and extracted by native-speaking reviewers or were translated into English using Google translate (Google, Mountain View, California) in their absence. Non-English language full texts provided as image files via interlibrary loan were converted to PDF and then run through optical character recognition software in order to facilitate Google translation *(25–27)*. All discrepancies were resolved through discussion between reviewers and disagreements were arbitrated by a third reviewer. Following extraction, data were represented in characteristics tables and then synthesized in aggregate quantitatively and qualitatively, and summary of findings tables, where applicable, were generated using the GRADEpro Guideline Development Tool (Cochrane United Kingdom). Where outcomes were reported inconsistently or different types of data were collected and reported, narrative synthesis was completed.

Data analysis. Continuous variables were collected and reported as sample sizes, means with standard deviations, mean differences, medians with ranges and interquartile ranges where applicable. Dichotomous or categorical variables (for example, presence of mosquito, presence of adverse event) were collected and reported as frequencies and proportions with 95% confidence intervals when provided. Continuous outcomes (mean difference) and dichotomous outcomes (relative risk and odds ratio) were collected when available, and reported in summary of findings tables, only when the primary study included a comparator group, using a standardized measure of treatment difference. Odds ratios reflect the odds of mosquito death in the experimental (exposed) arms compared to the odds of mosquito death in the control (unexposed) study arms, and were used to generate forest plots using PRISM v9.0 (GraphPad, La Jolla, CA). Similarly, relative risk reflects the risk of mosquito death in the experimental (exposed) arms compared to the risk of mosquito death in the control (unexposed) arms. Summary estimates of both continuous and dichotomous outcomes were pooled for each combination of disinsection (across methods, insecticide formulations, conveyance settings and participants) and efficacy and, where applicable, safety outcome. Level of significance was set at a 5% alpha level for summary estimates of outcomes measured against a comparator. Statistical analysis was carried out using GRADEpro GDT (McMaster University, 2014), PRISM v.9.0 (GraphPad, La Jolla, CA), and Review Manager (RevMan, computer program, version 5.3. Copenhagen: the Nordic Cochrane Centre, the Cochrane Collaboration, 2014).

2.5 Health equity assessment

We evaluated the included literature for key health equity factors listed according to the acronym PROGRESS, which includes place of residence, race/ethnicity, occupation, gender/sex, religion, education, socioeconomic status and social capital, as well as additional relevant stratifiers such as sexual orientation, marital status and gestational factors *(28)*. We also identified other health equity and human rights stratifiers as being of particular relevance to COVID-19 and aviation, represented by the acronym CANDALS – citizenship; ability; neurotypicality or neurodiversity; disability; age; literacy and/or fluency in a universal language of aviation; and size, body mass index (BMI) or body habitus *(29)*. Studies of humans, notably for outcome 2 – safety, toxicity and tolerability – were reviewed for any description of, or data stratification by, the PROGRESS-CANDALS factors.

2.6 Methodological quality assessment and risk of bias

Risk of bias and certainty of evidence. Comprehensive risk of bias forms adapted from the Joanna Briggs critical appraisal tools were designed, and subsequently utilized independently and simultaneously by two reviewers to carry out the bias assessment *(30)*. The GRADE framework was followed to assess methodological quality, assigning each included study a quality grade of high, moderate, low, or very low, based on apparent level of bias *(22, 23)*. Discrepancies were resolved through discussion and in the case of non-agreement by a tertiary arbitrator. If outcomes were not reported or incompletely reported, or if the assessments were only obtained subjectively (such as by self-report of adverse event, for example), studies were considered at risk for reporting and/or information/outcome bias, respectively. Bias assessments were pooled and an overall risk of bias score was achieved per study. A pooled assessment of bias risk was assigned based on the adequacy or inadequacy of – where applicable – allocation, concealment, blinding, attrition and completeness of reporting by one reviewer and verified by a second reviewer. Study quality was reported using heatmaps, generated by the software RevMan.

Where relevant, additional GRADE parameters such as inconsistency, indirectness and imprecision of outcomes, as well as levels of publication bias and plausible confounding, effect size and relevant dose response gradients, were also considered when grading certainty of evidence. Certainty was planned to be upgraded by one additional unit if a large effect size (< 0.5 or > 2) was evident, or by two additional units if a very large effect size (< 0.2 or > 5) was reported. Overall, risk of bias was then considered alongside these additional GRADE parameters to generate a final certainty of evidence GRADE score, per reported outcome.

For outcome 1 – efficacy of disinsection as measured by mosquito mortality – many of the quality assessment elements of GRADE are not applicable, as the study participants were mosquitoes and the desired outcome was mortality. As such, the elements of participant blinding, loss to follow-up, and participant non-adherence to the intervention are not applicable. As such, a novel quality assessment checklist (Annex 4) was developed by four study authors based on the WHO *Guidelines for testing the efficacy of insecticide products used in aircraft (31)*, which enabled study authors to score each disinsection trial across multiple domains of study design and implementation in order to achieve a composite grade of methodological rigour. The checklist contains five major sections scoring studies across 36 domains of methodological quality in accordance with the guidelines. If studies adhered to a particular recommendation, they received 1 point for that domain. If studies did not adhere to a particular recommendation, they received no points for that domain. If partial adherence occurred, then studies received 0.5 points for that domain. As not all domains were relevant to all study designs, studies were scored only on the domains to which they could have theoretically adhered, and then assigned a percentage adherence score. For example, a disinsection study trialling an insecticide at "blocks away" would not have been scored on the domains only relevant to pre-embarkation disinsection procedures.

Where common outcomes (such as insecticidal efficacy) were reported by more than one study of similar design (for example, use of same insecticide in a similar setting), forest plots were generated for pooled odds ratios of mosquito mortality collectively and across subgroups, including mosquito species, model of conveyance, method of disinsection and type of insecticide using GraphPad PRISM v.9.0 (GraphPad, La Jolla, CA).

Sources of anticipated effect heterogeneity that would influence the efficacy outcome, in particular, encountered in this systematic review include genus (for example, *Aedes* vs *Anopheles*) and species (for example, *Ae. aegypti* vs *Ae. albopictus*) of mosquito; pathogen carriage vs non-carriage (for example, dengue, chikungunya or Zika virus detected in mosquito vector or not); type, formulation and concentration of insecticide applied (for example, 2% permethrin vs 2% d-phenothrin); air filtration system operational at the time of insecticide application and number of air exchanges per unit time on conveyance; model of conveyance to which insecticide was applied (for example, Airbus vs Boeing models of aircraft); climatic factors, including ambient temperature, humidity, ultraviolet exposure, cabin pressure and altitude at which insecticide was applied; and the point in time of travel at which the insecticide was applied (for example, pre-embarkation vs time of descent). The process of disinsection is, by nature, multistep, with variability inherent to persons applying the insecticide, and as such would be considered a "complex intervention". Additionally, the participants to which disinsection was applied (that is, mosquitoes) are highly likely to be variably located around the space to which the intervention is applied in real life (that is, stationary and hidden or enclosed vs airborne), and may be of different species with highly variable susceptibilities to insecticides, and as such would themselves introduce complexity. Insecticides are unlikely to be uniformly applied by persons of variable height, strength and stride cadence. Dispersion of insecticide is likely to be affected by the aforementioned climatic and ambient cabin factors, including the operation of the air conditioner, as is recommended *(31)*. All such factors were collected in as granular a manner as was reported by the primary study, and summarized in the study characteristics tables. An absence of this degree of granularity was noted in the limitations of data generalizability and applicability section of the descriptive text.

3. Systematic review findings

3.1 Literature search

Of 8610 unique studies identified by our search, 505 proceeded to full-text screening, at which point 398 were excluded for failing to fulfil inclusion criteria (Figure 2). Of 107 unique included reports or studies (with 13 reporting more than one main outcome), 19 reported the primary efficacy outcome of mosquito mortality; 21 reported the primary safety and toxicity outcomes of human adverse events, toxicity, subjective tolerability, morbidity or mortality; and 80 reported the secondary outcomes of identification of mosquitoes aboard (n=52 studies) or in proximity to international conveyances at points of entry (n=28 studies).

3.2 Included studies

Tables 3 to 6 report the characteristics of included studies according to study design, intervention and reported outcomes. Table 3 pertains to studies evaluating the efficacy of disinsection with the primary reported outcome of mosquito mortality. Table 4 pertains to studies reporting the human safety, toxicity and tolerability of aircraft disinsection with primary reported outcomes of morbidity, adverse health events, objective measures of toxicity and subjective measures of tolerability (perceived effects). Table 5 pertains to studies reporting on mosquito detection aboard international conveyances, with the primary reported outcome of adult mosquito presence identified. Table 6 pertains to studies reported on mosquito detection at international points of entry, with the primary reported outcome of adult mosquito presence identified. Other outcomes of interest – including user acceptability, operational efficiency, impact on public health and health systems, financial impact, effects on equipment, feasibility, legal considerations, political and sociocultural considerations, insecticide resistance, and carriage of pathogens – are reported in the corresponding table (Tables 3–5) from which the data were derived. Given the overlap of tolerability (as a signal for a human health impact) and user acceptability (as a signal for preferences with or without health impacts), studies reporting either are represented in the corresponding category across tables. For example, malodour may reflect inhalation of a harmful substance with a health impact, in which case it would be represented under tolerability; or it may be benign, in which case it would be represented under user acceptability. Given the lack of objective toxicity data underpinning much of the data around user preferences, such reports are noted under both outcomes.

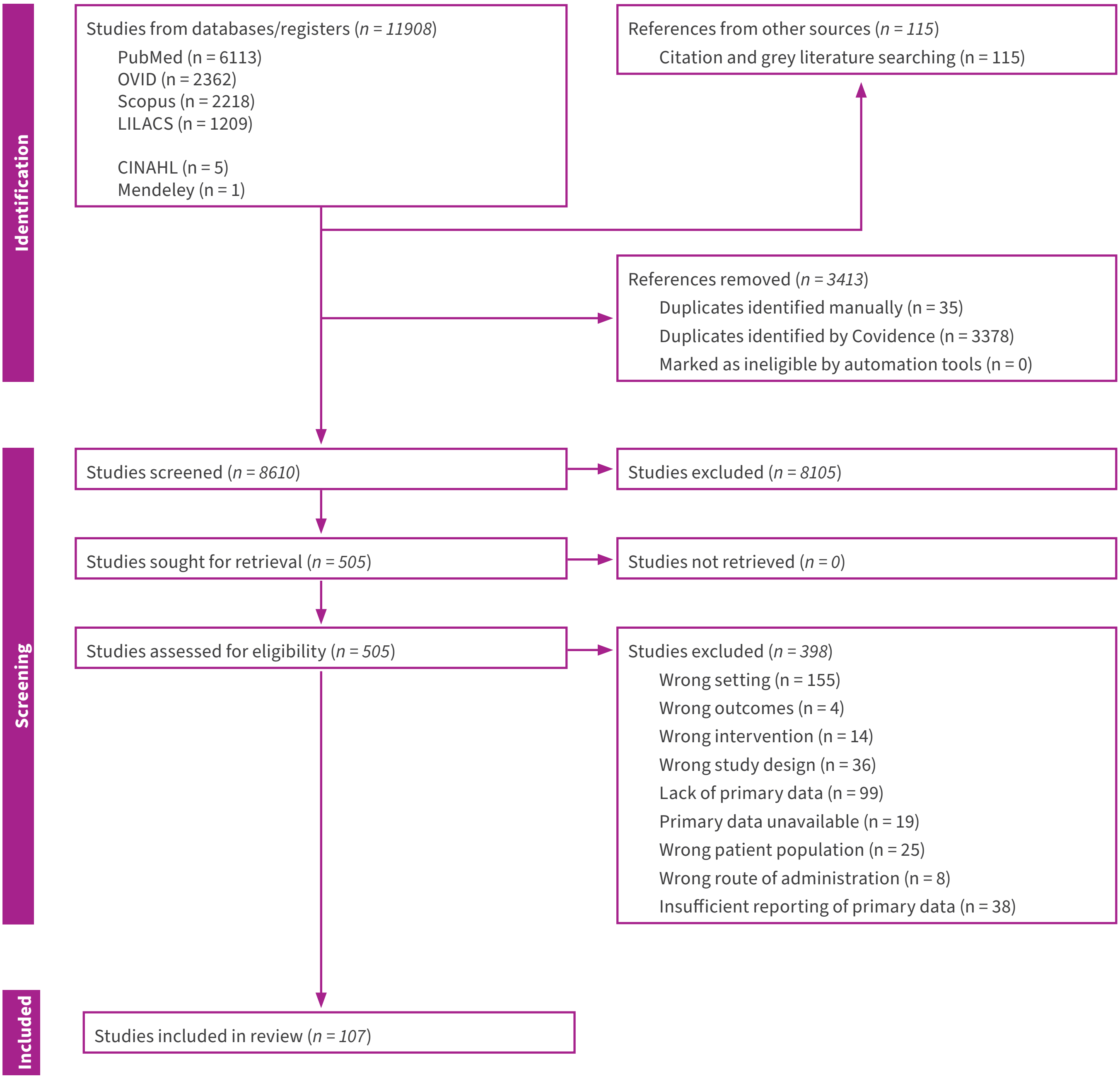
3.3 Efficacy of disinsection

Nineteen studies of disinsection of conveyances fulfilled study inclusion (Table 3), 18 of which addressed aircraft disinsection only, while one addressed both aircraft and transport truck disinsection *(32)*. No studies of mosquito disinsection efficacy on marine vessels, rail or spacecraft were identified. Of 19 studies of aircraft disinsection, five studies reported on pre-embarkation methods, including residual disinsection (four studies) *(33–36)* and pre-boarding aerosol disinsection (two studies) *(33, 34)*, while 11 reported on the methods of "blocks away" *(32, 37–46)* and two on "top of descent" spraying *(33, 47)*. An additional four studies reported on alternative methods of disinsection, including immediately after take-off *(48)* or upon arrival *(47)*, or other unparticularized methods *(49, 50)*. Nine of the 19 studies included a comparator arm of unexposed mosquitoes *(32, 33, 37, 39, 40, 42, 44–46)*, and as such permitted calculation of the main efficacy outcomes of both absolute and relative mosquito mortality, with calculated odds ratios and relative risks of mortality in the intervention versus control groups.

Of the nine comparator studies included, four evaluated one of the insecticides currently recommended for use in aircraft disinsection procedures, as follows: four studies evaluated 2% d-phenothrin *(32, 33, 40, 46)*, and no studies evaluated 2% 1R-trans-phenothrin or 2% permethrin. Additionally, three studies evaluated 0.1%–2% resmethrin *(37, 44, 45)*, one study evaluated 1–2% allethrin *(44)*, two studies evaluated 0.05%–2% bioresmethrin *(37, 44)*, and four studies evaluated various concentrations of pyrethrins in combination with Tropital synergist (1.6%–2.7%) *(37, 44)* or DDT (1.17%–3%) *(37, 39, 42)*.

Of the nine comparator studies included, seven evaluated the efficacy of aircraft disinsection against *Aedes* spp. of mosquitoes *(32, 33, 37, 40, 42, 44, 46)*, six against *Anopheles* spp. of mosquitoes *(32, 33, 40, 42, 44, 46)*, and six against *Culex* spp. of mosquitoes *(32, 33, 39, 40, 42, 45)*. Amongst comparator trials evaluating aircraft disinsection efficacy, five studies used

Figure 2. PRISMA flow diagram of literature evaluated for inclusion in systematic review of mosquito disinsection of international conveyances and surveillance of mosquitoes aboard conveyances and at points of entry



Boeing aircraft 707, 727 and 747 *(32, 33, 39, 40, 44)*, one used Airbus 310 aircraft *(33)*, three used de Havilland D-6, D-8 or Comet aircraft *(37, 42, 44)*, two used Lockheed aircraft *(45, 46)*, and one study used each of BAC aircraft *(44)*, Vickers Viscount aircraft *(42)*, and Sud Caravelle aircraft *(42)*. Amongst comparator (that is, mosquito-controlled) trials evaluating disinsection efficacy, eight studied the "blocks away" methodology *(32, 37, 39, 40, 42, 44–46)* and one studied pre-embarkation aerosol spraying *(33)* as well as pre-embarkation residual application to surfaces *(33)*.

3.4 Human safety and toxicity of disinsection

Twenty-one studies evaluating the human safety, toxicity and tolerability of aircraft mosquito disinsection fulfilled inclusion criteria (Table 4), of which 11 were experimental trials without human control arms *(33, 37, 38, 40, 42–44, 49, 51–53)*, one was a case–control study with a comparator arm of unexposed Arizona residents *(54)*, one was a cohort study with both exposed and unexposed flight attendants *(55)*, five were case series *(56–60)*, one was a case report *(61)*, and two were review articles reporting primary data *(62, 63)*.

Of 21 studies evaluating or reporting on human safety, toxicity and tolerability of aircraft disinsection of mosquitoes, three studies reported significant chronic morbidity *(54, 58, 60)*, three studies reported specific adverse events and health safety effects *(58, 60, 61)*, 12 studies reported objective signs or biological markers of toxicity *(33, 51–55, 57–61, 63)*, 11 studies reported on subjective symptoms in those exposed *(37, 40, 52, 54, 56, 58–63)*, and eight studies reported on subjective tolerability with or without subjective symptoms *(38, 40, 42, 44, 49, 60, 62, 63)*.

Credit: WHO
Surveillance of dengue vectors in Baghdad and Erbil - June 2021

Table 3A. Characteristics of included studies examining the efficacy of disinsection of vehicular conveyances

Author (year)	Study design	Country setting	Conveyance	Speciesa	Sample size	Insecticide used	Formulation	Disinsection method
Berger-Preiss (2006)	Experimental trial with comparator arm[b]	Germany	Grounded passenger aircraft (Airbus A310 and Boeing 747-400)	*Aedes aegypti*, *Anopheles stephensi*, *Culex pipiens*	Total: 9,566 Exposed: 8,921 Unexposed: 645 Initial: 1849 Residual: 7717 *A.a.* 4219 *A.s.* 1177 *C.p.* 4170	d-phenothrin	2% d-phenothrin	Simulated pre-flight, and top-of-descent spraying
Brooke (1971)	Experimental trial with comparator arm[b]	United Kingdom[2]	Grounded passenger aircraft (de Havilland Comet 4C)	*Aedes aegypti*	Total: 8000 Exposed: 7200 Unexposed: 800	bioresmethrin, resmethrin, pyrethrins, DDT, bioallethrin, Tropital	bioresmethrin: 0.05%, 0.075%, 0.1%, 0.25% resmethrin: 0.1%, 0.25%, 0.5% 0.4% pyrethrins + 3.0% DDT 0.45% pyrethrins 0.45% + 2.7% Tropital	Simulated blocks away with no passenger present
Cawley (1974)	Experimental trial	USA[3]	Commercial passenger aircraft (Boeing 707, Boeing 727)	*Culex pipiens fatigans* Wiedemann	ND	bioresmethrin, resmethrin, S-2539 Forte	bioresmethrin: 2% with 5% ethanol resmethrin: 0.3%, 1.2%, and 2% with 5% ethanol S-2539 Forte: 0.3%, 1.2%, and 2%	Blocks away
Jakob (1972)	Experimental trial	USA	Empty trailer trucks and unoccupied propeller-driven passenger aircraft	*Aedes aegypti*, *Anopheles albimanus*, *Anopheles quadrimaculatus*	ND	bromophos, carbaryl, chlorpyrifos, DDT, dtrans-allethrin, fenitrothion, fenthion, Gardona, Mobam, propoxur, pyrethrins, resmethrin, G-1707, G-1729, G-1730, G-1731	micronized dusts: 46.4% bromophos; 10% and 40% chlorpyrifos; 20% chlorpyrifos + 12.8% resmethrin; 13.3% chlorpyrifos + 8.5% resmethrin + 21.3% propoxur; 10% chlorpyrifos + 6.4% resmethrin + 16% propoxur + 20% Gardona; 42.5% DDT + 42.5% carbaryl; 14% d-trans-allethrin; 26.1% fenitrothion; 20.2% fenthion; 80% Gardona; 83.3% Mobam; 64% propoxur; 2.8% pyrethrins; 17% and 25.5% resmethrin aerosols: G-1707 (2.25% pyrethrins + 2.70% Tropital); G-1729 (2.25% pyrethrins + 2.70% sulfoxide); G-1730 (11% d-trans-allethrin); G-1731; 7.5% resmethrin	Simulated trials of residual and pre-flight spraying, without passengers on board
Jensen (1965)	Experimental trial	USA	Commercial passenger aircraft (DC-6B)	*Anopheles quadrimaculatus*	ND	dichlorvos vapour	air concentration ranged from 0.13 to 0.25 µg/L dichlorvos	Disinsection any time while aircraft is closed, and ventilation system is on

[2] United Kingdom of Great Britain and Northern Ireland
[3] United States of America

Author (year)	Study design	Country setting	Conveyance	Speciesa	Sample size	Insecticide used	Formulation	Disinsection method
Langsford (1976)	Experimental trial with comparator arm[b]	Australia	Passenger aircraft (Boeing 747)	*Culex fatigans*	Total: 330 Exposed: 260 Unexposed: 70	pyrethrins	0.4% pyrethrins + 1.6% piperonyl butoxide, with 10% iso-paraffin solvents and Freon 11 + 12 as propellants	Blocks away followed by saturation after disembarking
Liljedahl (1976)	Experimental trial with comparator arm[b]	USA	Commercial passenger aircraft (Boeing 707, Boeing 727)	*Aedes aegypti*, *Aedes taeniorhynchus*, *Anopheles quadrimaculatus*, *Anopheles stephensi*, *Culex pipiens fatigans*	Total: 5773 Exposed: 4677 Unexposed: 1096 *A.a.* 662 *A.t.* 2483 *A.q.* 1757 *A.s.* 351 *C.p.f.* 520	d-phenothrin	2% (+)-phenothrin in a 3:17 ratio of Freon-11 to 12 (break-off tip cans) and 2% (+)-phenothrin in a 1:1 ratio of Freon-11 to 12 (340 g cans with vertical release valves)	Blocks away
Mackie (1938)	Experimental trial	United Kingdom	Passenger aircraft (Imperial flying boat)	ND	ND	Deskito (pyrethrum)	pyrethrum water-based (1:14) insecticide with paraffin	Immediately after take-off
Ong (2018)	Experimental trial	Australia	Simulated aircraft environment	*Aedes aegypti* with 996P/1023G kdr mutation	ND	permethrin	0.2 g/m2 as target dose of permethrin	Residual treatment
Pimentel (1954)	Experimental trial	USA	Commercial aircraft (Convair-240, DC-3)	*Aedes aegypti*	~200	DDT, lindane	formulation not specified; insecticides were dissolved in methylcyclohexane	Residual treatment
Russell (1984)	Experimental trials[c]	Australia	Passenger aircraft (Boeing 707, Boeing 747)	*Culex quinquefasciatus*	1975–1976: ND 1978: ND 1980: 1500	d-phenothrin, pyrethrins	1975–1976: 0.4% pyrethrins + 1.6% piperonyl butoxide 1978: 2% d-phenothrin 2%; 0.4% pyrethrins + 1.6% piperonyl butoxide; 0.4% pyrethrins + 1.6% piperonyl butoxide + 0.4% d-phenothrin 1980: 2% d-phenothrin	Blocks away
Russell (1989)	Experimental trials[d]	Australia	Passenger aircraft (Boeing 747, Boeing 767)	*Culex quinquefasciatus*	20 per test site with 10–12 test sites per flight	d-phenothrin	2% d-phenothrin	Top of descent and on-arrival spraying

Author (year)	Study design	Country setting	Conveyance	Speciesa	Sample size	Insecticide used	Formulation	Disinsection method
Sullivan (1962)	Experimental trial with comparator arm[b]	Italy, Switzerland, United Kingdom, USA	Passenger aircraft (Boeing 707, Caravelle, Comet 4B, DC-6, DC-8, Viscount)	*Aedes aegypti*, *Anopheles gambiae*, *Anopheles stephensi*, *Culex fatigans*	Total: 7855 Exposed: 6574 Unexposed: 1281 *A.a.* 3157 *A.g.* 243 *A.s.* 1065 *C.f.* 3390	pyrethrum extract(s), pyrethrins, DDT	SRA: 1.60% pyrethrum extract (25% pyrethrins), 3.00% DDT, 7.50% xylene, 2.90% odourless petroleum distillate, 42.50% Freon-12, 42.50% Freon-11 G-1480: 3.40% pyrethrum extract (20% pyrethrins), 1.17% DDT, 4.50% aromatic petroleum derivative solvents, 63.62% Freon-12, 27.31% Freon-11	Blocks away
Sullivan (1964)	Experimental trial	Fiji, New Zealand, Philippines	Passenger aircraft (DC-3, DC-7C, DC-8, Fokker, Viscount)	*Aedes aegypti*, *Aedes albopictus*, *Culex fatigans*	ND	DDT, G-1492, pyrethrum extract(s), SRA	SRA: 1.60% pyrethrum extract (25% pyrethrins), 3.00% DDT, 7.50% xylene, 2.90% odourless petroleum distillate, 42.50% Freon-12, 42.50% Freon-11 G-1492: 6.00% pyrethrum extract (20% pyrethrins), 2.00% DDT, 8.00% xylene, 58.80% Freon-12, 25.20% Freon-11	Blocks away
Sullivan (1972)	Experimental trial with comparator arm[b]	USA (WHO)[4]	Commercial jet passenger aircraft (Boeing 747, Boeing 707, BAC 111, CD-8, DC-9)	*Aedes aegypti*, *Anopheles litoralis*, *Anopheles stephensi*, *Culex molestus*, *Culex pipiens fatigans*, *Culex pipiens pallens*	Total: 5076 Exposed: 4308 Unexposed: 768 *A.a.* 2035 *A.l.* 138 *A.s.* 207 *C.m.* 198 *C.p.f.* 2223 *C.p.p.* 275	bioresmethrin, G1707, resmethrin, pyrethrum extract(s), Tropital, (+)-trans-allethrin	resmethrin: 1.12% and 2.25% aerosols bioresmethrin: 1% and 2% aerosols (+)-trans-allethrin: 1.11% and 2.22% aerosols G-1707: 2.25% pyrethrum extract (20% pyrethrins, 2.70% Tropital synergist, 10.05% petroleum distillate, 59.90% Freon-12, 25.50% Freon-11)	Blocks away
Sullivan (1974)	Experimental trial with comparator arm[b]	USA	Tractor trailers and commercial aircraft (Boeing 707, Boeing 727)	*Aedes aegypti*, *Anopheles quadrimaculatus*	Total: 1162 Exposed: 602 Unexposed: 560 Tractors: 450 Airplanes: 712 *A.a.* 701 *A.q.* 461	d-phenothrin	1.2% d-phenothrin and 2.0% d-phenothrin (both in propellants Freon 11+12 50:50)	Blocks away without passengers

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Author (year)	Study design	Country setting	Conveyance	Speciesa	Sample size	Insecticide used	Formulation	Disinsection method
Sullivan (1975)	Experimental trial with comparator arm[b]	USA	Jet passenger aircraft (C-141, Lockheed)	*Culex quinquefasciatus Say*	Total: 378 Exposed: 315 Unexposed: 63	d-trans-resmethrin, resmethrin	1.20% resmethrin and 98.66% propellants 11+12 (ratios 50:50 and 30:70) 1.20% d-trans-resmethrin and 98.67% propellants 11+12 (50:50)	Blocks away
Sullivan (1978)	Experimental trial with comparator arm[b]	USA	Jet aircraft for pilot training (Lockheed)	*Aedes taeniorhynchus*, *Anopheles quadrimaculatus*	Total: 453 Exposed: 285 Unexposed: 168 *A.t.* 132 *A.q.* 321	d-phenothrin	water-based: 2.03% (+)-phenothrin (98.5%), 0.87% Span 80, 0.03% Tween 60, 30% propellants (80% isobutane, 20% propane), 67.07% deionized water Freon-based: 2.09% (+)-phenothrin (95.8%), 97.91% propellants (1:1 Freon 11+12)	Blocks away
Tew (1951)	Experimental trial	United Kingdom	Grounded Argonaut and Tudor type 2 aircraft	*Aedes aegypti*	200	DDT, pyrethrins	CMR 1: 0.4% pyrethrins and 3% DD CMR 2: 1.2% pyrethrins and 2% DDT CMR 3: 0.4% pyrethrins + 2% DDT + 3% piperonyl butoxide CMR 4: 0.4% pyrethrins and 3% piperonyl butoxide Am MS: 1.2% pyrethrins and 2% DDT Am. IS: 1.2% pyrethrins and 2% DDT	Simulated spraying in grounded aircraft, not specified

A.a. = *Aedes aegypti*, *A.t.* = *Aedes taeniorhynchus*, *A.g.* = *Anopheles gambiae*, *A.l.* = *Anopheles litoralis*, *A.s.* = *Anopheles stephensi*, *A.q.* = *Anopheles quadrimaculatus*, *C.f.* = *Culex fatigans* (now known as *Cx. quinquefasciatus*), *C.m.* = *Culex molestus*, *C.p.* = *Culex pipiens*, *C.p.f.* = *Culex pipiens fatigans* (now known as *Cx. quinquefasciatus*), *C.p.p* = *Culex pipiens pallens*.

a. Species names as reported in study regardless of present-day nomenclature (e.g. *Culex pipiens fatigans* now known as *Culex quinquefasciatus*).

b. Denotes experimental trials that have a comparator arm of unexposed mosquitoes, with both numerator and denominator data available for mosquito mortality.

c. Russell (1984) reports on the outcomes of three separate sets of trials: (i) 1975–1976, (ii) 1978, (iii) 1980. Primary data for each set of trials unavailable.

d. Russell (1989) reports on the outcomes of three separate sets of trials: (i) February 1986, (ii) 1986, (iii) July 1987. Primary data for each set of trials unavailable.

Table 3B. Characteristics of included studies examining the efficacy of disinsection of vehicular conveyances [continuation]

Author (year)	Insecticide resistance	Mosquito mortality	Other outcomes and comments	Adherence to WHO guidelinesa
Berger-Preiss (2006)		Twenty minutes after spraying (pre-embarkation method), mortality was 94–99.5% for *Aedes aegypti* and 100% for *Anopheles stephensi*. Residual efficacy of disinsection, assessed 7–48 hours after spraying, yielded mosquito mortality of 89–100% on horizontal surfaces and 13–100% on vertical surfaces. Mortality was 0–6% in control mosquitoes.	**User acceptability.** Pre-embarkation methods result in low dermal and inhalation exposures in passengers.	4/22 (18.18%)
Brooke (1971)		Disinsection with any insecticide yielded a mean mosquito mortality of 97–100%, compared with 12% in control studies. Mean mosquito mortality by insecticide was as follows: 97% for 0.05% bioresmethrin, 98% for 0.075% bioresmethrin, 99% for 0.1% bioresmethrin, 100% for 0.25% bioresmethrin, 99% for 0.1% resmethrin, 100% for 0.25% resmethrin, 100% for 0.5% resmethrin, 100% for 0.4% pyrethrins + 3% DDT, and 100% for 0.45% pyrethrins + 2.7% Tropital.		6/16 (37.50%)
Cawley (1974)		*Culex pipiens* mortality was tested on seats, floors and rack positions. Mean mosquito mortality across positions was as follows: 0.3% resmethrin (99.23, 65.42, 29.33), 0.3% S-2539 Forte (86.17, 61.92, 23.95), 1.2% resmethrin (100, 100, 0), 1.2% S-2539 Forte (91.73, 72.47, 71.36), 2.0% resmethrin (100, 97.69, 96.35), 2.0% S-2539 Forte (100, 100, 96.81), 2.0% bioresmethrin (100, 100, 100).	**User acceptability.** Crew reported that lower concentrations were least noticeable, and some found the odour pleasing. One compound, S-2539 Forte, was odourless.	5/16 (31.25%)
Jakob (1972)		All aerosol formulations achieved 100% mosquito mortality in both truck trailers and aircraft. Direct application of micronized dusts 40% chlorpyrifos, 17% and 25.5% resmethrin, and 20% chlorpyrifos + 12.8% resmethrin achieved 100% mosquito mortality in both truck trailers and aircraft. 64% propoxur and 2.8% pyrethrins achieved 100% mosquito mortality in truck trailers and 100% mortality in the front and centre positions on aircraft; however, mortality was decreased in rear positions (propoxur achieved 0–95% mortality in rear positions and pyrethrins achieved 46–49% in rear positions). Direct application of micronized dusts 83.3% Mobam, 10% chlorpyrifos, 46.4% bromophos, 26.1% fenitrothion, 20.2% fenthion, 14% d-trans-allethrin, 42.5% DDT + 42.5% carbaryl, 10% chlorpyrifos + 6.4% resmethrin + 16% propoxur + 20% Gardona, and 13.3% chlorpyrifos + 8.5% resmethrin + 21.3% propoxur achieved 100% mosquito mortality in truck trailers. Mobam achieved 99% mortality and Gardona achieved 88–100% mortality in truck trailers. Residual treatment with micronized dust 40% chlorpyrifos, 25.5% resmethrin, 20% chlorpyrifos + 12.8% resmethrin, 10% chlorpyrifos + 6.4% resmethrin + 16% propoxur + 20% Gardona, and 83.3% Mobam achieved 100% mosquito mortality in truck trailers. 64% propoxur achieved 100% mortality of *Anopheles* but only 80–96% mortality of *Aedes*. 17% resmethrin achieved 75–86% mortality of *Anopheles* and 0–7% mortality of *Aedes*. 2.8% pyrethrins achieved 0–5% mortality in both species. Mortality was "negligible" except three tests with 10–21% mortality of *Aedes albimanus*.	**Effects on equipment.** Micronized dusts accumulated on vertical surfaces of trailer. Authors suggest that dust deposits were sufficient enough that applications should be limited to situations where "appearance was not a factor".	5.5/16 (34.38%)

Author (year)	Insecticide resistance	Mosquito mortality	Other outcomes and comments	Adherence to WHO guidelines[a]
Jensen (1965)		100% mortality of *Anopheles quadrimaculatus* mosquitoes achieved on all six 30-minute flights in all tested compartments (pilot compartment, seat racks, galley, and baggage compartments). No mortalities occurred in control specimens.	**User acceptability.** Passengers did not show any awareness that an insecticide was being, or had been, dispensed. One crew member remarked: "You can't have passenger reaction when they don't see, hear or smell anything."	2.5/10 (25%)
Langsford (1976)		Initial in-flight spray at the end of the landing roll achieved 100% mortality in all stations at 12 and 24 hours. Initial in-flight spray followed by a second saturation spray after passengers disembarked also achieved 100% mortality in all stations at 12 and 24 hours. Control mosquito mortality was 0% at 12 hours and 5.71% at 24 hours (4 out of 70 control mosquitoes found dead). Authors suggest this was expected as mosquitoes had been in cups for 36 hours by this point.	**Feasibility.** Switching off air conditioning was deemed feasible given that passengers tolerated resultant temperature. However, authors note that short taxi time (< 4 minutes), low passenger load, and lower ambient temperature all contributed to lack of temperature rise in airplane upon taxiing. **Operational efficiencies.** All passengers were notified of timing of disinsection during pre-flight announcements. **User acceptability.** Air conditioning and individual passenger air outlets were shut off and cabin air was recirculated at the end of the landing roll, before disinsection. Resultant temperature conditions for passengers were deemed acceptable.	5/16 (31.25%)
Liljedahl (1976)		In a Boeing-727, application of 2% (+)-phenothrin from the break-off tip can achieved 100% mortality of *Anopheles quadrimaculatus* and 98–100% mortality of *Aedes taeniorhynchus*. Application from the 340 g vertical-release can achieved 98–100% mortality of *A. quadrimaculatus* and 93–100% mortality of *A. taeniorhynchus*. Mortality of control mosquitoes was 12–13% of *A. quadrimaculatus* and 0–6% of *A. taeniorhynchus*. In a Boeing-707, application from the 340 g vertical-release can achieved 89–100% mortality of *Anopheles stephensi*, 93–100% mortality of *Aedes aegypti*, and 82–100% mortality of *Culex pipiens fatigans*. Mortality of control mosquitoes was 0% of *A. stephensi*, 1% of *A. aegypti*, and 0% of *C.p. fatigans*.	**User acceptability.** No odour or irritation from disinsection or residual deposit noticed by crew or scientists over 14 treatments.	6/17 (35.29%)
Mackie (1938)		In one experiment, 100% mosquito mortality was achieved within 2–11 minutes of spraying. In a second experiment, all but two mosquitoes were dead by 24 hours; the two mosquitoes alive at 24 hours died "an hour or so later".	**Operational efficiencies.** Minor defects noted in structure of apparatus or method of using it; however, these were "readily overcome" with experience. **User acceptability.** Demonstrations of aircraft disinsection were "favourably commented on by the majority of observers". **Other.** Water-based pyrethrum insecticide was chosen, as paraffin-based insecticides are flammable. One particular insecticide, "aircraft pyagra", was not chosen, given paraffin base along with unpleasant "after-effects".	4.5/16 (28.13%)

Author (year)	Insecticide resistance	Mosquito mortality	Other outcomes and comments	Adherence to WHO guidelinesa
Ong (2018)	Resistant *Aedes aegypti* colony at 100% 996P/1023G kdr mutation frequencies was used as a proxy for mosquitoes intercepted at Australian airports. No mortality data reported for resistant mosquito colony.	Bioassays performed on permeable surfaces with 0.2 g/m^2 permethrin achieved mortality of < 50% in susceptible mosquitoes exposed for 30 minutes. Patchily treated environments typical of treated aircraft cabins and holds do not result in the universal exposure of mosquitoes in simulated environments.	**Comment.** Unclear if the study was conducted in aircraft, or on various aircraft surfaces (e.g. carpets) in a laboratory setting. **Operational efficiencies.** Permethrin recovery from surfaces was considerably less than applied amount.	NA[d]
Pimentel (1954)		DDT applied to baggage compartments did not provide satisfactory kill of mosquitoes (75% mortality 1 week after treatment, down to 18% mortality 5 weeks after treatment). Lindane, at various concentrations, applied to baggage and passenger compartments achieved 98–100% mortality up to 5 weeks after treatment, and 83–100% mortality up to 8 weeks after treatment.	Effects on equipment. Lindane produced "objectionable spotted surfaces" in passenger compartments at 200 mg/ft^2, so lower doses had to be tested.	2.5/9 (27.77%)
Russell (1984)[b]		1975–1976 trials (0.4% pyrethrins + 1.6% piperonyl butoxide): B707 trial (November 1975, Auckland/Sydney) achieved 100% mosquito mortality. B747 trials (November 1975, Auckland/Sydney, and March 1976, Melbourne/Sydney) achieved less than 100% mosquito mortality (actual percentage not specified). 1978 trials (2% d-phenothrin, 0.4% pyrethrins + 1.6% piperonyl butoxide, and 0.4% pyrethrins + 1.6% piperonyl butoxide + 0.4% d-phenothrin): in a parked B747 in Sydney airport, 100% mortality was observed after 18 hours in all but "one exception". Authors report "virtually 100% mosquito mortality". No stratification by insecticide formulation reported. 1980 trials (2% d-phenothrin): in B747 Standard and Combi aircraft, 99.8% (1497/1500) mosquito mortality was achieved at 24 hours at fixed stations. Eleven single "wild cups", or randomly placed cups aiming to target less accessible locations in the aircraft, achieved 100% mortality (N not specified). Control mosquitoes had 0% mortality in 38 stations and 10–30% mortality in 8 stations (N not specified).	**Effects on equipment.** Qantas experienced problems with electronic equipment on B747s, which "appeared to be attributable" to d-phenothrin. Commissioned 1978 trials with the goal of removing second on-arrival spray to decrease the amount of insecticide residue deposited. **Operational efficiencies.** As a motivation for the 1980 trials, Qantas requested the government to consider a single-spray blocks away method on New Zealand–Australia flights due to continued delays with on-arrival spraying. **User acceptability.** 1978 trials excluded bioresmethrin and resmethrin as test agents due to side-effects, namely offensive odour. In these trials, the two pyrethrin-based sprays had highly irritant respiratory effect on personnel. **Other.** Following the 1978 Qantas trials, the recommendation was made to amend disinsection protocols in Australia to a single spray of 2% d-phenothrin at 10 g/1000 ft^3. This protocol became practice. Following the 1980 Qantas trials, the recommendation was made that blocks away should achieve sufficient mortality; however, it was not introduced in practice due to "other considerations".	6/17 (35.29%)

Author (year)	Insecticide resistance	Mosquito mortality	Other outcomes and comments	Adherence to WHO guidelinesa
Russell (1989)[c]		February 1986 trials: B747-300 from Singapore to Sydney, disinsected with 2% d-phenothrin via top of descent spraying with the air conditioning on, achieved 100% mortality of *Culex* mosquitoes. 1986 trials: B747-200 from Singapore to an unspecified Australia airport, disinsected with 2% d-phenothrin via on-arrival spraying with the air conditioning on, achieved 100% mortality of *Culex* mosquitoes. July 1987 trials: B767 from Sydney to Brisbane, disinsected with 2% d-phenothrin via top of descent spraying, achieved 100% mortality of mosquitoes.	**Operational efficiencies.** Authors note that top of descent disinsection eliminates delays associated with on-arrival disinsection. **User acceptability.** With blocks away, some passengers expressed concerns about allergic reactions to insecticides. Authors suggest top of descent obviates these concerns due to proximity of touchdown and ensuing medical attention. Authors report that top of descent disinsection "in general" is accepted by passengers. **Other.** Following trials, Australian Government accepts Qantas top of descent procedure. They report all countries except New Zealand accepted this approach.	11.5/19 (60.50%)
Sullivan (1962)	On London flights, DDT-resistant and susceptible *Aedes aegypti* were used. SRA achieved 0–33% mortality in DDT-resistant strains (compared to 81–100% mortality in susceptible strains). G-1480 achieved 0% mortality in one cage and 100% mortality in two cages of DDT-resistant mosquitoes (compared to 0% mortality in one cage and 100% mortality in four cages of susceptible strains). In the cage with 0% mortality of both resistant and susceptible mosquitoes, it was placed directly in front of an air inlet. On Rome flights, DDT-resistant *Culex fatigans* were used. SRA achieved 0–100% mortality in one flight, 58–100% mortality in another flight, and 33–87% mortality in a training flight. G-1480 achieved 100% mortality in one flight and 27–65% mortality in a training flight (only 3/5 intended dosage used on the training flight).	G-1480 achieved 100% mortality of susceptible and resistant mosquitoes in all but two trials (in one trial, only 3/5 of proper dosage was used; in another trial, the mosquito cages with decreased mortality were placed directly in front of an air inlet). Control mosquito mortality was 0–5%. SRA achieved 90–100% mortality in most trials of susceptible mosquitoes. SRA failed to achieve adequate mortality of DDT-resistant *Aedes* or *Culex* mosquitoes (see "Insecticide resistance" column). Control mosquito mortality was 0–4%.	**Operational efficiencies.** Disinsection at blocks away eliminated 10 min. aircraft delay. Blocks away is suitable from the standpoint of crew availability for disinsection in relation to their other responsibilities. Fixed position aerosols are more expensive and complicated to install. **User acceptability.** No unfavourable reaction to SRA in any test. Unfavourable reactions to G-1480 (higher pyrethrum) on all flights with use. Objections were noted to be "marked in some instances" with an "irritant effect". In one test, aerosol insecticide dripped onto one passenger.	8.5/18 (47.22%)

Author (year)	Insecticide resistance	Mosquito mortality	Other outcomes and comments	Adherence to WHO guidelinesa
Sullivan (1964)	In the Philippines trials (Philippine mosquitoes), *Aedes* spp. had an increased tolerance to DDT (2–3 times the level of normal strains), as determined by susceptibility testing. *Culex fatigans* were presumed resistant to DDT. G-1492 was more effective than SRA against resistant Philippine mosquitoes, achieving 100% mortality in 4/5 flights versus 100% mortality in 9/14 flights using SRA.	G-1492 was more effective than SRA against resistant Philippine *Aedes* spp. and *Culex* mosquitoes. G-1492 achieved 100% mortality in 4/5 flights (84–94% in remaining one flight). SRA achieved 100% mortality in 9/14 flights, 96–100% mortality in 2/9 flights, and 40–100% mortality in 2/9 flights. G-1492 and SRA both achieved 100% mortality in susceptible Fiji *Culex* mosquitoes. Controls "in general" had 0–25% mortality, but was reported as high as 36–57% in "very few tests".	**Feasibility.** Crew found dispensers to be awkward to handle in the DC-8 aircraft (better with use of larger volume dispensers). **Operational efficiencies.** Two dispensers malfunctioned and needed to be replaced; disinsection interfered with safety briefings. Authors suggest it may be advisable to forewarn passengers about temporary nasal dryness after insecticide application. **User acceptability.** Passengers reported no irritation with SRA spray. The stewardesses who applied the SRA formulation indicated a certain preference for it compared with the G-1029 formulation used in the 1961 trials.	6.5/17 (38.24%)
Sullivan (1972)	*Culex pipiens fatigans* resistant to DDT: 2% d-trans-allethrin achieved 100% mortality in the cabin and lavatory, and 0% mortality in the cockpit. G-1707 achieved 81% mortality in the cabin. *Culex pipiens fatigans* resistant to organophosphates: 2% resmethrin achieved 99% mortality in the cabin.	Authors arbitrarily selected mortality of 97% as an acceptable level for the cabin. Only three of average mortality levels were lower than 97% (1% resmethrin at 94.2%, 1% d-trans-allethrin at 96.4%, and G-1707 at 94.9%) and in each case the confidence interval contained the 97% point. Mortality in lavatories was acceptable with 1% resmethrin and 2% d-trans-allethrin (100%). Mortality in lavatories was not acceptable with 2% resmethrin (43.8%), 1% d-trans-allethrin (85.2%), 1% bioresmethrin (30%), or G-1707 (75%). There was no acceptable mortality in the cockpit when tested (2% resmethrin achieved 33.3% mortality, and 2% d-trans-allethrin and 2% bioresmethrin both achieved 0% mortality). Control mosquito mortality was 0% in all trials except for three, with mortality ranging from 4–8%. In authors' opinion, 2% resmethrin aerosol at blocks away appears to be the optimal procedure for disinsecting aircraft.	**User acceptability.** Passengers were surveyed as to whether they (a) liked or did not care, or (b) disliked the treatment. (b) was then adjusted for the proportion who judged the control treatment to be unpleasant. 2% resmethrin: 92.06% liked or did not care, 7.94% disliked (0% adjusted). 1% resmethrin: 100% liked or did not care. 2% d-trans-allethrin: 64.71% liked or did not care, 35.29% disliked (29.03% adjusted). 1% d-trans-allethrin: 98% liked or did not care, 2% disliked (0% adjusted). 2% bioresmethrin: 71.82% liked or did not care, 28.18% disliked (21.23% adjusted). 1% bioresmethrin: 89.80% liked or did not care, 10.20% disliked (1.51% adjusted). G-1707: 84.81% liked or did not care, 15.19% disliked (6.99% adjusted).	6.5/18 (36.11%)
Sullivan (1974)		100% mortality of *Anopheles quadrimaculatus* was achieved in aircraft and tractor trailers with 1.2% phenothrin; 0% mortality in controls. 100% mortality of *Aedes aegypti* was also achieved in tractor trailers with 1.2% phenothrin; however, 79% mortality was seen in controls and invalidated the results for *A. aegypti*. 100% mortality of *Aedes aegypti* and *Anopheles quadrimaculatus* was achieved in Boeing aircraft (707 and 727) with 2% phenothrin. Control mosquito mortality was 0% for *A. aegypti* and 8% for *A. quadrimaculatus*.	**User acceptability.** in aircraft tests, two pilots and three scientists reported no odour or irritation after treatments.	5.5/19 (28.94%)

Author (year)	Insecticide resistance	Mosquito mortality	Other outcomes and comments	Adherence to WHO guidelinesa
Sullivan (1975)		100% mortality of *Culex* mosquitoes was achieved on all three flights with use of 1.2% resmethrin and 1.2% d-trans-resmethrin. Control mosquito mortality ranged from 0–25% (0% on two flights, 8% on one flight, and 25% on one flight).	**User acceptability.** In room tests used to determine odours from residual deposits of pyrethroids, 4.5–40% of respondents noted a “slightly unpleasant odour” and 5–15% noted an “unpleasant odour”. Pretreatment values were 15.4–38.4% “slightly unpleasant odour” and 0–7.7% “unpleasant odour”. In seven aircraft tests with resmethrin, ½ hour before landing, a “slightly unpleasant odour” was detected from 0–14.8% of respondents (versus 0–27% before spraying) and an “unpleasant odour” was detected from 0–8% of respondents (versus 0–1.6% before spraying).	7.5/18 (41.66%)
Sullivan (1978)		100% mortality of *Aedes taeniorhynchus* and *Anopheles quadrimaculatus* was achieved in all five trials with mosquitoes (two water-based aerosols at blocks away, two Freon-based aerosols at blocks away, and one Freon-based aerosol on a grounded aircraft). Control mosquito mortality was 6% in *A. taeniorhynchus* and 14% in *A. quadrimaculatus.*	**Effects on equipment.** There were no deleterious effects on any components of aircraft or its internal structure.	5/18 (27.77%)
Tew (1951)		In the Heathrow experiments with caged mosquitoes, Am. MS achieved 71–85% mortality, CMR 1 achieved 83–100% mortality, CMR 2 achieved 85–100% mortality, and Am. IS achieved 85–100% mortality. Control mosquito mortality was observed at 36% in experiments 1–6 and 40% in experiments 7–10. In the Farnborough experiments, both caged and free-flying mosquitoes were used. On the first day of experiments with caged mosquitoes, CMR 1 (dose reduced from 15 g/1000 ft^3 to either 5 or 10 g/1000 ft^3) achieved 99.5–100% mortality and CMR 3 achieved 100% mortality. On the second day of experiments with caged mosquitoes, CMR 1 (dose reduced to 5 g/1000 ft^3) achieved 46% mortality with a closure time of 3 minutes and 69% mortality with a closure time of 5 minutes. CMR 4 achieved 65% mortality (closure time 5 minutes). On both days with free-flying mosquitoes, CMR 1 achieved 100% mortality (four tests), CMR 3 achieved 100% mortality, and CMR 4 achieved 99.5% mortality. Caged control mosquito mortality was observed at 0–2% in mosquitoes exposed in aircraft and 0–7% in mosquitoes in untreated aircraft. Higher mortality was noted with 5-minute closure versus 3-minute closure. Higher mortality was observed in free-flying mosquitoes versus caged mosquitoes.	**Operational efficiencies.** Am. MS had very rapid output that made even distribution difficult; dose was distributed in a “rather compact cloud”. **Other.** Authors observed very different mortality rates with Am. IS, Am. MS and CMR 2, which of all contained the same amount of DDT and pyrethrins. Authors suggest that dispenser may be as important as insect formulation.	5.5/16 (34.38%)

DDT: dichlorodiphenyltrichloroethane; SRA: standard reference aerosol; µg/L: micrograms per litre.

a. Percentage adherence to a formulated checklist representing WHO *Guidelines for testing the efficacy of insecticide products used in aircraft (31)*.

b. Russell (1984) reports on the outcomes of three separate sets of trials: (i) 1975–1976, (ii) 1978, (iii) 1980. Primary data for each set of trials unavailable.

c. Russell (1989) reports on the outcomes of three separate sets of trials: (i) February 1986, (ii) 1986, (iii) July 1987. Primary data for each set of trials unavailable.

d. Ong (2018): unable to calculate adherence to WHO disinsection guidelines as study methods could not be evaluated on abstract alone (no published full text available).

Table 4A. Characteristics of included studies examining the safety and toxicity of disinsection of vehicular conveyances

Author (year)	Study design	Country setting	Conveyance	Population	Sample sizes	Mean age (SD)	Range	Sex N (F:M)	Insecticide used	Formulation	Disinsection method
Berger-Preiss (2006)	Experimental trial	Germany	Grounded passenger aircraft (Airbus A310 and Boeing 747-400)	Study personnel	4–6	ND	ND	ND	d-phenothrin	d-phenothrin 2%	Simulated pre-flight and top of descent spraying
Berger-Preiss (2004)	Experimental trial	Germany	Passenger aircraft (Airbus A310)	Study personnel	4–6	ND	ND	ND	pyrethrum extract(s), pyrethrins	1.25% pyrethrum extract (containing 25% pyrethrins, active ingredients), synergist piperonyl butoxide (2.6%), and the propellants butane and propane	Simulated in-flight spraying method in grounded aircraft
Bitelli (1969)	Review	Italy	Passenger aircraft	Passengers, crew	ND	ND	ND	ND	DDT	ND	ND
Bonta (2003)	Case series	USA[5]	Passenger aircraft (Boeing 747-400)	Flight attendants, passengers, pilots	38	ND	ND	ND	permethrin	ND	Residual treatment
Brooke (1971)	Experimental trial	United Kingdom[6]	Grounded passenger aircraft (de Havilland Comet 4C)	Authors, engineers	6	ND	ND	ND	bioresmethrin, resmethrin, pyrethrins, DDT, bioalletrhin, Tropital	bioresmethrin: 0.05%, 0.075%, 0.1%, 0.25%; resmethrin: 0.1%, 0.25%, 0.5%; pyrethrins 0.4% + DDT 3.0%; pyrethrins 0.45% + Tropital 2.7%	Simulated blocks away without passengers present
De Tavel (1967)	Review	Switzerland	ND	Volunteers	ND	ND	ND	ND	dichlorvos	ND	ND
Edmundson (1970)	Case series	USA	Commercial aircraft	Aircraft disinsection technicians	4	49	37–60	0:4	pyrethrins, DDT	Aerosol containing 3% DDT and 1% pyrethrin	Not specified
Kilburn (2004)	Case–control	USA	Passenger aircraft	Flight attendants	E: 33 NE: 202	E: 47.7 (6.9) NE: 45 (21.1)	E: 32–60 NE: ND	ND	pyrethroids	Not specified	Residual treatment
Liljedahl (1976)	Experimental trial	USA	Commercial passenger aircraft (Boeing 707, Boeing 727)	Authors, crew	At least 18	ND	ND	ND	d-phenothrin	2% (+)-phenothrin in a 3:17 ratio of Freon-11 to 12; and in a 1:1 mixture of Freon-11 to 12	Blocks away

[5] United States of America
[6] United Kingdom of Great Britain and Northern Ireland

Author (year)	Study design	Country setting	Conveyance	Population	Sample sizes	Mean age (SD)	Range	Sex N (F:M)	Insecticide used	Formulation	Disinsection method
Maddock (1961)	Experimental trial	USA	Commercial aircraft	Study personnel	4	ND	ND	ND	dichlorvos	Not specified	Simulated in-flight spraying method in grounded aircraft
Przyborowski (1962)	Case series	Poland	Ship	Crew members	20	ND	ND	ND	dieldrin	Liquid preparation stored in tins and wooden crates	Contaminated food stores
Smith (1972)	Experimental trial	USA	Simulated aircraft (altitude chamber)	Staff volunteers, paid participants	8	ND	21–40	2:6	dichlorvos	Not specified, but product was 5–10 times higher than median value typically prescribed for disinsection	Top of descent (8000 ft simulation)
Sutton (2007)	Case series	USA	Commercial aircraft	Flight attendants	12	ND	ND	ND	permethrin	permethrin 2.2% (25:75 cis:trans)	Residual treatment
Vanden Driessche (2010)	Case report	Netherlands (Kingdom of the)	Passenger aircraft	Passenger	1	29	29	1:0	d-phenothrin	d-phenothrin, tetrafluoroetane, C11-15-iso-alkanes, methoxypropoxypropanol, peach perfume	Blocks away
Wei (2012)	Cohort	USA	Commercial aircraft	Flight attendants	11 exp. 17 unexp.	ND	18–65	ND	Permethrin	Not specified	Residual treatment
Woodyard (2001)	Case series / news report	USA	Passenger aircraft	Passengers, flight attendants, pilots	9	ND	ND	5:4	permethrin, in one case only	Not specified	Residual treatment
Cawley (1974)[a]	Experimental trial	USA	Commercial passenger aircraft (Boeing 707, Boeing 727)	Crew members	ND	ND	ND	ND	bioresmethrin, resmethrin, S-2539 Forte	bioresmethrin: 2% with 5% ethanol; resmethrin: 0.3%, 1.2%, and 2% with 5% ethanol; S-2539 Forte: 0.3%, 1.2%, and 2%	Blocks away
Jensen (1965)[a]	Experimental trial	USA	Commercial passenger aircraft (DC-6B)	Passengers, crew	28–45 per 6 flights	ND	ND	ND	dichlorvos vapour	Air concentration in the range 0.13–0.25 µg/L dichlorvos	Disinsection any time while aircraft is closed, and ventilation system is on

Author (year)	Study design	Country setting	Conveyance	Population	Sample sizes	Mean age (SD)	Range	Sex N (F:M)	Insecticide used	Formulation	Disinsection method
Sullivan (1962)[a]	Experimental trial	Italy, Switzerland, United Kingdom, USA	Passenger aircraft (Boeing 707, Caravelle, Comet 4B, DC-6B, DC-8, Viscount)	Passengers, crew	ND	ND	ND	ND	DDT, G-1480, pyrethrum extract(s), SRA	SRA: 1.60% pyrethrum extract (25% pyrethrins), 3.00% DDT, 7.50% xylene, 2.90% odourless petroleum distillate, 42.50% Freon-12, 42.50% Freon-11; G-1480: 3.40% pyrethrum extract (20% pyrethrins), 1.17% DDT, 4.50% aromatic petroleum derivative solvents, 63.62% Freon-12, 27.31% Freon-11	Blocks away
Sullivan (1964)[a]	Experimental trial	Fiji, New Zealand, Philippines	Passenger aircraft (DC-3, DC-7C, DC-8, Fokker, Viscount)	Passengers, flight attendants	ND	ND	ND	ND	DDT, G-1492, pyrethrum extract(s), SRA	SRA: 1.60% pyrethrum extract (25% pyrethrins), 3.00% DDT, 7.50% xylene, 2.90% odourless petroleum distillate, 42.50% Freon-12, 42.50% Freon-11; 6.00% G-1492: pyrethrum extract (20% pyrethrins), 2.00% DDT, 8.00% xylene, 58.80% Freon-12, 25.20% Freon-11	Blocks away
Sullivan (1972)[a]	Experimental Trial	USA (WHO)	Commercial jet passenger aircraft (B-747, B-707, BAC 111, CD-8, DC-9)	Passengers	591 int. 68 con.	ND	ND	ND	bioresmethrin, G-1707, resmethrin, pyrethrum extract(s), Tropital, (+)-trans-allethrin	resmethrin: 1.12%, and 2.25% aerosols; bioresmethrin: 1%, and 2% aerosols; (+)-trans-allethrin: 1.11%, and 2.22% aerosols; G-1707: pyrethrum extract (20% pyrethrins) 2.25%, Tropital synergist 2.70%, petroleum distillate 10.05%, Freon-12 59.50%, Freon-11 25.50%	Blocks away

a. Studies reporting only subjective tolerability.

Table 4B. Characteristics of included studies examining the safety and toxicity of disinsection of vehicular conveyances [continuation]

Author (year)	Morbidity, adverse events, objective signs of toxicity, and subjective symptoms	Other
Berger-Preiss (2006)	**Objective signs of toxicity.** The pre-embarkation method resulted in lower dermal exposures, while top of descent spraying resulted in lower inhalation exposures for both sprayers and passengers. However, during the pre-embarkation method of spraying, exposure is reduced to 0.1–0.5% of that of top of descent, for persons boarding 20 mins following termination of disinsection. Urine metabolites of d-phenothrin were detected at concentrations of 0.62–1.21 µg/L, and 0.11 µg/L for persons entering the cabin 10 mins after spraying. Overall, the potential inhalation and dermal exposures from disinsection are lower than the acceptable daily intake for d-phenothrin (ADI = 0.07 mg/kg bw).	**User acceptability.** Pre-embarkation methods result in low dermal and inhalation exposures in passengers.
Berger-Preiss (2004)	**Objective signs of toxicity.** Calculated inhaled doses for sprayers: 3–12 µg pyrethrins; for passengers: 4–17 µg pyrethrins. Calculated dermal doses for sprayers: 200-830 µg pyrethrins per person; for passengers: 120-300 µg pyrethrins per person. Active ingredients determined on individual body parts strongly varied. For sprayers, left upper arm and forearm were the most affected body parts (maximum 24 µg pyrethrins); while for passengers it was the head and thighs (maximum 15 µg pyrethrins).	**Comments.** Study personnel wore protective breathing masks and clothing; reported study was not suitable to monitor health symptoms.
Bitelli (1969)	**Subjective symptoms.** Aerosol disinsectants could cause skin irritation, irritate the mucous membranes and, if in sufficiently high quantities, can cause systemic effects such as nausea, vomiting, fatigue and other nervous system manifestations. **Subjective tolerability.** Passengers complained of “heavy air” and unpleasant odours, especially for longer procedures, including pre-embarkation disinsection.	**Comments.** DDT mentioned but not directly linked to study personnel. **User acceptability.** Passengers complained of “heavy air” and unpleasant odours, especially for longer procedures, including pre-embarkation disinsection.
Bonta (2003)	**Subjective symptoms.** 38 self-reports consistent with exposure to pyrethroid pesticides on 237 flights, of which 95% followed residual spray applications.	**Operational efficiencies.** 13 flights involving “problems” with the in-flight spray were documented by the Association of Flight Attendants (AFA). **Effects on equipment.** Visible residue of 2.2% permethrin on the cabin floor of one flight. **User acceptability.** Personal protective equipment (PPE) was not recommended for flight attendants; training included one page of information, and a fact sheet distributed by airline. **Public health impact.** Health agencies recommended to evaluate the effectiveness of disinsection and investigate non-toxic methods; airlines recommended to educate and monitor the health of workers and passengers regarding disinsection hazards, restrict worker access to aircraft post-disinsection, stop spraying in crew rest areas, ensure maximum ventilation, implement quality control for pesticide applications, and schedule flights to minimize the number of treated aircraft.
Brooke (1971)	**Subjective symptoms.** Acute respiratory discomfort caused by pyrethrins/Tropita1 to the authors and four engineers.	
De Tavel (1967)	**Subjective symptoms.** No adverse effect on reaction or visual performance noted. **Objective signs of toxicity.** No alterations of blood cholinesterase levels noted. **Subjective tolerability.** Dichlorvos spares irritation of eyes and air passages.	**User acceptability.** Dichlorvos spares irritation of eyes and air passages.

Author (year)	Morbidity, adverse events, objective signs of toxicity, and subjective symptoms	Other
Edmundson (1970)	**Objective signs of toxicity.** Participant A had little change in DDT and DDE levels; levels were comparable to general population of the area (DDT x < 4 ppb, DDE x 9 ppb, DDA x < 2 ppb) – higher than in the general population but less than in the other participants. Participants B, C, and D showed a rise of DDT (14 ppb; 11 ppb; 24 ppb) and DDE (9 ppb; 7 ppb; 24 ppb) on the first day and then stabilized to ~4/5 ppb of their mean level in (participant B and D) and ~10 ppb in (participant C, respectively). Statistical analyses were not presented; however, authors suggest that concentrations of DDT, DDE and DDA were unrelated to either the amounts of aerosol used in a day or to time spent in actual spraying.	
Kilburn (2004)	**Morbidity.** Five flight attendants retired due to disability. **Objective signs of toxicity.** Impaired balance, decreased grip strength in left arm and colour discrimination in both eyes; total abnormalities: 2.8 ± 3.5 in E group vs 1.2 ± 1.6 in NE group; $P = 0.001$. **Subjective symptoms.** Flight attendants exposed to disinsection were significantly more likely to report higher frequencies of neurological perturbation, respiratory issues, gastrointestinal discomfort, dermatologic abnormalities, and sensory complaints. The profile of mood states (POMS) average score was also significantly higher in exposed attendants (52 vs 21), indicating increased depression, tension, fatigue, confusion, and decreased vigour. Additionally, exposed attendants reported numb fingers (n=18), anaemia (n=16; not quantified), sun-induced rash (n=13), and excessive hair loss (n=12), although no control comparison was provided. The average symptom frequency was 5.0 in exposed attendants compared to 2.6 in non-exposed attendants.	
Liljedahl (1976)	**Subjective symptoms.** Irritation was not reported by study participants. **Subjective tolerability.** Odour due to disinsection was not reported by study participants.	**User acceptability.** Odour due to disinsection was not reported by study participants.
Maddock (1961)	No subjectively reported symptoms or objective signs of toxicity were reported by study personnel.	
Przyborowski (1962)	**Morbidity.** Twelve persons were hospitalized for at least a few days; two for 3 weeks. **Adverse event.** Seizures (n=14). **Objective signs of toxicity.** Vitals: hypertension, bradycardia (n=3); labs: hypochloraemia, serum bilirubin elevated or at ULN; imaging: encephalogram (n=1) showing signs of epileptic type; approximately 70% of samples tested were positive for dieldrin contamination. **Subjective symptoms.** Gastrointestinal: vomiting, nausea, abdominal cramps; neurological: headache, dizziness, convulsions (involving brief loss of consciousness, frothing at the mouth, face contortions, biting of tongue and lips, and severe back spasms), falls (with loss of consciousness), dizziness, severe weakness, limb paralysis, blurred vision, tremors, isolated muscle contractions; psychiatric: severe agitation, mania; musculoskeletal: myalgia (n=1); systemic: fever (n=2); dermatologic: bruising and contusions associated with falls.	**Operational efficiencies.** Cleaning and washing of warehouses required. Food products on board ship were destroyed.
Smith (1972)	**Objective signs of toxicity.** A statistically significant difference in the effect of dichlorvos on plasma or erythrocyte cholinesterase activity, palmar sweating, dark adaptation, and bronchiolar resistance, between ground level, altitude without dichlorvos, and altitude with dichlorvos was not detected. No evidence that dichlorvos at exposure levels far in excess of those proposed for disinsection possesses toxicity at 8000 ft, a cabin altitude which is seldom exceeded in normal airline operations involving pressurized aircraft.	

Author (year)	Morbidity, adverse events, objective signs of toxicity, and subjective symptoms	Other
Sutton (2007)	**Objective signs of toxicity.** Specific signs of toxicity included runny nose (n=1), wheeze (n=1), eye conjunctivitis (n=2), and skin erythema/flushing (n=1). **Subjective symptoms.** The most common signs and symptoms experienced were respiratory (n=12), nervous system (n=11), dermatologic (n=9), eye (n=9), cardiovascular (n=5), and gastrointestinal (n=6).	
Vanden Driessche (2010)	**Adverse event.** Anaphylaxis. **Objective signs of toxicity.** After spraying, passenger developed facial erythema, slightly oedematous eyes, pronounced lip swelling, and prolonged expiration. Blood pressure and heart rate were normal. **Subjective symptoms.** Passenger developed diarrhoea and feeling of losing consciousness shortly after cabin spraying. Symptoms improved with inhaled albuterol and oral corticosteroids. Subsequent non-disinsection exposures to pyrethroid-containing compounds caused wheezing and itchy, swollen eyelid.	
Wei (2012)	**Objective signs of toxicity.** Flight attendants on disinsected flights showed significantly higher levels of metabolites immediately post-flight and 24 hours later, compared to pre-flight levels. Creatinine-adjusted concentrations of 3-PBA in post-flight samples were in the range 2.18–-71.0 µg/g, decreasing to 1.20–19.2 µg/g after 24 hours, while non-disinsected flights showed no significant changes. Flight attendants on disinsected flights also had higher pre-flight metabolite levels than those on non-disinsected flights. There was no significant difference between non-disinsected flights and the general population. The highest levels were found in flights to/from Australia compared to US domestic and other international flights.	
Woodyard (2001)	**Morbidity.** Three flight attendants retired due to disability. **Adverse event.** Blood cell disease reported by one flight attendant. **Objective signs of toxicity.** One flight attendant reported below-normal oxygen retention. **Subjective symptoms.** Passengers, flight attendants and pilots reported burning eyes (n=2), severe nausea, headaches, burning skin (n=2), itchy eyes (n=2), loss of appetite (n=2), acute rash (n=2), difficulty breathing (n=2), short-term memory loss (n=3), difficulties concentrating, tremors, nosebleeds, long-term disability (n=3), impaired ability to fly (n=2), congested sinuses, sore throat, difficulties swallowing and confusion. **Subjective tolerability.** Passengers, flight attendants and pilot complain about odour, actively try to escape disinsection.	**User acceptability.** Passengers, flight attendants and pilot complain about odour, actively try to escape disinsection. **Legal.** Three lawsuits related to disinsection were filed: passengers and employees against United Airlines, and an attorney against five insecticide manufacturers. Only information about the first lawsuit is available. The court, under the Warsaw Convention, ruled that injuries from normal plane operations are not accidents. Since disinsection was routine for United Airlines and legally required by Australia, the plaintiffs argued it was "unexpected" and an accident. However, the court decided that disinsection is a necessary part of ordinary operations, even if passengers were not informed, therefore dismissing the case.
Cawley (1974)[a]	**Subjective tolerability.** Lower concentrations were less noticeable, some found odour pleasing, and S-2539 Forte was odourless.	**User acceptability.** lower concentrations were less noticeable, some found odour pleasing, and S-2539 Forte was odourless.
Jensen (1965)[a]	**Subjective tolerability.** None of the passengers on any flight showed awareness (viewed, heard or smelled) that disinsection occurred.	**User acceptability.** None of the passengers on any flight showed awareness (viewed, heard or smelled) that disinsection occurred.
Sullivan (1962)[a]	**Subjective tolerability.** Unfavourable reactions to SRA aerosol were not identified; whereas G-1480 received unfavourable reactions, given a higher pyrethrum content.	**Operational efficiencies.** Disinsection at blocks away eliminated 10 min. aircraft delay. **User acceptability.** Unfavourable reactions to SRA aerosol were not identified; whereas G-1480 received unfavourable reactions, given a higher pyrethrum content.

Author (year)	Morbidity, adverse events, objective signs of toxicity, and subjective symptoms	Other
Sullivan (1964)[a]	**Subjective symptoms.** Irritation from SRA aerosol was not reported by study participants, while G-1492 caused nasal dryness in a few passengers.	**Operational efficiencies.** Disinsection interfered with safety briefings.
Sullivan (1972)[a]	**Subjective tolerability.** A statistically significant passenger objection rate to higher doses of active material (1% vs 2%) was reported (6.21±7.17 and 23.26±4.39, respectively). Passenger objection to resmethrin 2% was the same as the control, suggesting 2% resmethrin was the best material tested.	**User acceptability.** A statistically significant passenger objection rate to higher doses of active material (1% vs 2%) was reported (6.21±7.17 and 23.26±4.39, respectively). Passenger objection to resmethrin 2% was the same as the control, suggesting 2% resmethrin was the best material tested.

ADI: acceptable daily intake; con: control group; DDA: dichlorodiphenylacetic acid; DDE: dichlorodiphenyldichloroethylene; DDT: dichlorodiphenyltrichloroethane; E: exposed to disinsection; ft: feet; int: intervention group; mg/kg bw: milligrams per kilogram of body weight; ND: no data; NE: not exposed to disinsection; PBA: 3-phenoxybenzoic acid; pg: picogram; ppb: parts per billion; SRA: standard reference aerosol; µg: microgram; ULN: upper limit of normal.

a. Studies reporting only subjective tolerability.

3.5 Secondary and other outcomes related to disinsection

A total of 41 studies reported secondary or other outcomes of interest, including:

- user acceptability (19 studies) *(32, 33, 38–45, 47–49, 56, 60, 62–65)*;
- effects on equipment (five studies) *(34, 36, 41, 46, 56)*;
- operational efficiencies (16 studies) *(35, 41–43, 47, 48, 50, 58, 63, 65–71)*;
- financial impact to passengers and fiscal considerations in general (three studies) *(66, 72, 73*);
- feasibility (two studies) *(43, 63)*;
- carriage of pathogens (four studies) *(66, 74–76)*;
- public health or health systems impact (seven studies) *(56, 65, 72, 73, 77–79)*;
- legal considerations (two studies) *(60, 80)*;
- political or sociocultural considerations (two studies) *(65, 81)*;
- presence of insecticide resistance (two studies) *(35, 80)*,

with no studies reporting on the *development* of insecticide resistance (the outcome of interest) causally related to aircraft disinsection (Tables 3–6).

In addition to the above-noted studies reporting secondary and other outcomes related to disinsection, the WHO 2018 consultation report on *Methods and operating procedures for aircraft disinsection (8)* also describes issues of operational efficiency, user acceptability, feasibility and effects on equipment. The consultation report represented inputs from stakeholders, including ICAO, International Air Transport Association (IATA), various departments of health, biosecurity, and the environment, airport regulatory authorities, academics, as well as British Airways and Lufthansa.

No studies or identified grey literature reported on other outcomes of significant interest, including security; ethical issues; health equity and human rights issues; or impact on the environment.

3.6 Surveillance identification of mosquitoes on conveyances

A total of 51 studies reporting the identification of adult mosquitoes on conveyances fulfilled our inclusion criteria (Table 5), including 34 studies that reported mosquitoes aboard aircraft *(3, 41, 64–67, 70–72, 74, 77, 79, 82–103)*, nine that reported mosquitoes aboard marine vessels *(68, 69, 75, 80, 104–108)*, five that reported mosquitoes aboard both air and marine conveyances *(63, 73, 81, 109, 110)*, and one study that reported mosquitoes aboard dhows, trains, and aircraft *(78)*. We further included one report describing two mosquitoes found aboard spacecraft departing from Kennedy Space Center in Florida *(111)*.

Additionally, we included one report on true airplane malaria where there was no travel history conferring risk, no vector-competent mosquitoes active or endemic to the region, identification of *Anopheles* mosquitoes aboard the aircraft occurred, and transmission by any mechanism other than on the aircraft was implausible *(112)*.

3.7 Surveillance identification of mosquitoes at points of entry or in proximity of conveyances

A total of 28 studies reporting on the identification of adult mosquitoes at international points of entry or in proximity to international conveyances fulfilled our inclusion criteria (Table 6), including 12 studies reporting mosquitoes at airports *(35, 74, 99, 113–121)*, three studies reporting adult mosquitoes at seaports *(122–124)*, six studies reporting adult mosquitoes at airports and seaports *(63, 125–129)*, one study reporting adult mosquitoes at airports, seaports and highways *(130)*, one report of mosquitoes identified at an American naval submarine base *(76)*, and finally one study reporting adult mosquitoes at railways *(131)*. We also included one report of a mosquito surviving 18 months outside the International Space Station *(132)*.

Included in the 28 studies reporting surveillance data at international points of entry were four reports on airport malaria where included cases had no travel history, no vector-competent mosquitoes endemic to the region, and transmission by any mechanism other than on or near an aircraft was implausible in at least some of the included cases *(116, 133–135)* (Table 6).

Among surveillance studies identifying mosquitoes at *airports*, eight were conducted in Europe *(113, 114, 117, 125, 126, 128–130)*, three were conducted in southeast Asia *(118, 120, 121)*, two were conducted in Hawaii, United States of America *(115, 119)*, two were conducted in Australia *(35, 127)*, two were conducted in sub-Saharan Africa *(99, 116)*, and one study was conducted in each of North Asia *(74)*, South America *(99)*, and the Caribbean *(63)*. Among surveillance studies identifying mosquitoes at *seaports*, five were conducted in Europe *(125, 126, 128–130)*, two were conducted in Australia or New Zealand *(122, 127)*, two were conducted in North America *(76, 124)*, one was conducted in the Caribbean *(63)*, and one was conducted in sub-Saharan Africa *(123)*. Surveillance identifying adult mosquitoes at *railways* occurred in Europe *(131)*, as did surveillance identifying adult mosquitoes at points of entry on motorways in Europe *(130)*.

Credit: WHO / Halldorsson
Verano Monumental Cemetery in Rome, Italy, is an ideal breeding ground for Aedes albopictus – the Tiger mosquito – due to the hundreds of thousands of flower pots with stagnant water, scattered across the cemetery. The Tiger mosquito can transmit dengue virus to humans.

Table 5A. Characteristics of included empirical studies of mosquitoes carried by international conveyances

Author (year)	Study design	Country setting	Conveyance	Point of entry	Route of travel	Conveyances surveyed (n)	Total detected (n)	Seasonality
Air conveyances								
Carneiro de Mendonca (1947)	Surveillance report	Brazil	Aircraft	Belém, Fortaleza, Natal and Recife (Brazil)	Africa to Brazil	Flying boats (831), landplanes (10 698)	352	Season 1: 1939–1941 Season 2: 1942–1944
Cimerman (1997)	Case report	Brazil	Aircraft	Brazil	Lebanon to São Paulo (Brazil) via Abidjan (Côte d'Ivoire)	1	4	31 Aug– 4 Sep 1996
Danis (1996)	Surveillance report	Belgium, France, Germany, Italy, Netherlands (Kingdom of the), Spain, Switzerland, United Kingdom[7]	Aircraft	London (United Kingdom)	Rome (Italy) to London (United Kingdom)	NS	2	NS
Dethier (1945)	Surveillance report	Central Africa	Aircraft	Parked planes between India and west coast of Africa	Parked planes between India and west coast of Africa	11	10	1943–1945
Duguet (1949)	Review	Various countries	US Public Health Service: aircraft (civilian and military)	US Public Health Service: Miami, Florida 1946: Miami, Florida, San Juan, Puerto Rico, Brownsville, Texas, Honolulu, Hawaii (USA)	NS	US Public Health Service: 26 694 1946: 21 830	US Public Health Service: 2343 (168 alive) 1946: NS; 4% of flights transported mosquitoes, averaging 160/100 aircraft	1939–1944 and 1946
Evans (1963)	Surveillance report	USA[8]	Aircraft	Moisant International Airport (New Orleans), Honolulu International Airport (Hawaii), Miami International Airport (Florida) (found in luggage hold and passenger cabins)	NS	New Orleans: 210 Hawaii: 89 Florida: 1831 Total: 2130	New Orleans: 88 Hawaii: 32 Florida: 100 Total: 220	NS

[7] United Kingdom of Great Britain and Northern Ireland
[8] United States of America

Author (year)	Study design	Country setting	Conveyance	Point of entry	Route of travel	Conveyances surveyed (n)	Total detected (n)	Seasonality
Farrell (1948)	Review, surveillance report	Brazil	Aircraft	Brazil	South America to West Africa; included USA army posts in Nigeria, Gold Coast*, Liberia, and Senegal	NS	NS	Oct 1943
Goh (1995)	Surveillance report	Singapore	Aircraft	Changi Airport (Singapore) (found in passenger cabins)	Indian subcontinent	330	100	Jan 1983–Jan 1984
Gratz (2000)	Review	Pillai (1984): New Zealand Ogata (1974): Tokyo (Japan) Mayers (1983): Bermuda	Aircraft	Pillai (1984): New Zealand Ogata (1974): Tokyo (Japan) Mayers (1983): Bermuda	Pillai (1984): Fiji Ogata (1974): NS Mayers (1983): NS	NS	NS	Pillai (1984): 1970–1974 Ogata (1974): 1972–1973 Mayers (1983): 1983
Griffitts (1931)	Surveillance report, experimental trial	USA	Aircraft experiment: Fokker Trimotors, Sikorsky amphibians, and Commodores	Surveillance: between Miami (USA) and airports in Cuba, Haiti, Dominican Republic, Puerto Rico, Colombia, Panama, El Salvador, British Honduras (now Belize), Honduras, Yucatan (Mexico), and Jamaica Experiment: San Juan (Puerto Rico) to Santo Domingo (Dominican Republic) to Port-Au-Prince (Haiti) to Miami (USA) via Camaguey (Cuba) (found in luggage hold)	Surveillance: Cuba, Haiti, Dominican Republic, Puerto Rico, Colombia, Panama, El Salvador, British Honduras (now Belize), Honduras, Yucatan (Mexico), Jamaica Experiment: San Juan (Puerto Rico) to Santo Domingo (Dominican Republic), Dominican Republic to Port-au-Prince (Haiti), Haiti to Camaguey (Cuba), Cuba to Miami (USA)	Surveillance: 102	Surveillance: NS	Surveillance: 23 July–12 Sep 1931 Experiment: Sep 1931 (trial 1: 13 Sep, trial 2: 16 Sep, trial 3: 18 Sep)
Hedrich (2024)	Cross-sectional study	Switzerland	Passenger aircraft	Zürich Airport	Morocco, Cabo Verde, Puerto Rico, Dominican Republic, Costa Rica, Nicaragua, South Africa, Mauritius, Middle East, Sri Lanka, Oman, Maldives	37	0	NS

Author (year)	Study design	Country setting	Conveyance	Point of entry	Route of travel	Conveyances surveyed (n)	Total detected (n)	Seasonality
Highton (1970)	Surveillance report	Kenya	Aircraft	Nairobi Airport (Kenya)	West Africa, Ethiopia, North Africa, the Indian subcontinent, the Far East, Europe, and within East and Central Africa; Aden (South Yemen*) to Nairobi (Kenya) via Mumbai (India), London (United Kingdom), Nairobi (Kenya), via Frankfurt (Germany) and Entebbe (Uganda)	92	493	Mar–Apr 1968; Nov 1968–Jul 1969
Hughes (1949)	Surveillance report	USA	Aircraft	Miami, Brownsville, Honolulu, New Orleans, Terminal Island, and Fort Worth (USA), San Juan (Puerto Rico)	Several international flights to the USA	At least 22 656; mosquito-specific data NS	Alive: 817 Dead: 12 008 Total: 12 825	1938–1947
Hutchinson (2005)	Surveillance report	United Kingdom	Aircraft	Gatwick Airport (United Kingdom) (found in luggage hold in passenger cabin)	Accra (Ghana), Abuja (Nigeria), Entebbe (Uganda), Harare (Zimbabwe), Lagos (Nigeria), Nairobi (Kenya)	52	3	Jun–Sep 2001
Karch (2001)	Surveillance report	France	Passenger aircraft	Roissy Airport (France) (found in passenger cabin, walkway, cargo hold)	Brazzaville (Congo), Ndjamena (Chad), Douala (Cameroon)	42	5	Aug–Sep 2000
Laird (1951)	Surveillance report	New Zealand	Aircraft (military and civilian)	Whenuapai Airport (New Zealand)	NS	16	28	1946–1948
Laird (1952)	Surveillance report	New Zealand	Aircraft (Douglas Dakotas, Skymasters, Commandos, Constellations, Lancastrians, and Bristol freighters)	Whenuapai Airport (New Zealand)	Fiji, Norfolk Island (Australia), Australia, Cook Islands to Auckland (New Zealand)	3	4	Mar–Dec 1951
Le Maitre (1983)	Surveillance report	Trinidad and Tobago	Aircraft	Piarco International Airport (Trinidad and Tobago)	Brazil, Guadeloupe (France), Puerto Rico, Venezuela*), Grenada, Barbados, Suriname, and Colombia to Trinidad and Tobago	NS	50	1965–1974
Moreland (1991)	Surveillance report	United Kingdom	Aircraft	Heathrow Airport, (London) (found in cargo holds, luggage holds, passenger cabins)	Malaria risk areas, countries NS	NS	NS	Jan–Mar

Author (year)	Study design	Country setting	Conveyance	Point of entry	Route of travel	Conveyances surveyed (n)	Total detected (n)	Seasonality
Năstoiu (1988)	Review	Various countries	Aircraft	Lomonaco (1961): Cyprus WHO (1961): Miami, Florida (USA), Philippines WHO (1971): Hawaii (USA)	Lomonaco (1961): Tripoli (Libya) WHO (1961): NS WHO (1971): NS	Lomonaco (1961): 1 WHO (1961): NR. Philippines flights sampled over 5 years WHO (1971): NS	Lomonaco (1961): 1 WHO (1961): 1502 (305 alive) in USA; NS, but 84% were alive in Philippines WHO (1971): 65 (52 alive)	Lomonaco (1961): NS WHO (1961): NS WHO (1971): 1964–1968
O'Rourke (1950) [unpublished report]	Surveillance report	Ireland	Aircraft	Shannon Airport (Clare), Dublin Airport (Dublin)	Gander and Goose Bay (Canada), Paris (France), Amsterdam (Netherlands (Kingdom of the)), Lisbon (Portugal), London (United Kingdom), Dorval (Canada), Copenhagen (Denmark), Prestwick (United Kingdom), Brussels (Belgium), New York (USA), Bovington (United Kingdom), Stephenville (Canada), Liverpool (United Kingdom)	Clare: 122 Dublin: 19 Total: 141	5	Clare: 17 Jun–11 Jul; 9–30 Sep Dublin: 23–25 Sep
Pemberton (1944)	Surveillance report	USA	Aircraft	Pearl City (Honolulu), Canton Island (Kiribati), Midway Island, Hawaii (USA)	California (USA), Hong Kong Special Adminstrative Region (SAR) (China) or Manila (Philippines) via Guam, and Wake and Midway Islands (USA); New Zealand via New Caledonia (France), Fiji, and Canton Island*	California: 321 Asia/Pacific: 301 Total: 622	California: 88 (7 alive) Asia/Pacific: 211 (4 alive) Total: 299	Mar–Dec 1941
Russell (1984)	Surveillance report	Australia	Aircraft (BAC111, B707, VC9, Hawker-Sidley)	Darwin, Brisbane, Sydney, Perth (Australia) (found in cockpits, passenger cabins)	Surabaya, Denpasar, Koepang (Indonesia) to Australia	307	686	Survey 1: Dec 1938–Oct 1941 Survey 2: Feb 1974–Mar 1979
Russell (1987)	Experimental Study	Australia	Aircraft (Boeing 747B)	Sydney, Melbourne, Singapore, and Bangkok airports	ND	ND	ND	7 Aug 1986; 9–10 Aug 1986
Scholte (2010)	Case Series	Netherlands (Kingdom of the)	Aircraft	Schiphol Airport (Netherlands (Kingdom of the)) (found in passenger cabin)	São Paolo (Brazil) to Dar es Salaam (United Republic of Tanzania) to Schiphol (Netherlands (Kingdom of the))	ND	4	Mid-Nov 2008

Author (year)	Study design	Country setting	Conveyance	Point of entry	Route of travel	Conveyances surveyed (n)	Total detected (n)	Seasonality
Scholte (2014)	Surveillance report	Netherlands (Kingdom of the)	Aircraft	Schiphol Airport (Netherlands (Kingdom of the)) (found in aircraft cabins)	Amsterdam (Netherlands (Kingdom of the)) to Accra (Ghana), Dar es Salaam (United Republic of Tanzania), Entebbe (Uganda), Kilimanjaro (United Republic of Tanzania), Lagos (Nigeria), Nairobi (Kenya), Bangkok (Thailand), Dubai (United Arab Emirates), Hidd (Bahrain), Kuwait, Khartoum (Sudan), Kuala Lumpur (Malaysia), Miami (USA), Mumbai (India), New Delhi (India), Paramaribo (Suriname), Taipei (Taiwan, China)	38	13	Aug 2010–Oct 2011
Smith (1984)	Review	Various countries	Aircraft	Kisumu (Kenya), Durban (South Africa), Brownsville (Texas, USA), San Juan (Puerto Rico), Manila (Philippines), Haneda (Japan), Australia, Honolulu, Houston, Miami, New York (USA)	Kenya, South Africa, Philippines, Japan, Australia, and various USA states to Sudan and Uganda	NS	At least 19 510	Several years
Sukeriho (2013)	Surveillance report	Japan	Passenger aircraft	Narita International Airport	Manila (Philippines)	ND	1	Apr–Nov
Takahashi (1984)	Surveillance report	Japan	Aircraft	Tokyo International Airport (Narita) and Haneda (Japan)	Several international flights to Japan with layovers in tropical or subtropical regions	928	840 (568 females)	May 1975–Dec 1981
Thellier (2001)	Case report	France	Aircraft	Roissy Charles de Gaulle Airport	Angola to France	1	ND	NS
Welch (1939)	Surveillance report	USA	Aircraft (seaplane)	Pan American Airport, Dinner Key, Miami, Florida (USA)	Central America, South America, and Mexico to Florida	110	45 (5 alive)	NS
Whitfield (1939)	Review	Various countries	Aircraft	Khartoum (Sudan) (found under seats and in dark corners) James (1934): Kisumu and Nairobi (Kenya) Public Health Service at Miami (1936): Miami (USA)	South Africa, West Africa, Eritrea, Cairo (Egypt) James (1934): NS Public Health Service at Miami (1936): NS	James (1934): 30 Public Health Service at Miami (1936): 69	James (1934): ~57–125 Public Health Service at Miami (1936): 13 (11 alive)	Jul 1935–Aug 1938 James (1934): NS Public Health Service at Miami (1936): NS

Author (year)	Study design	Country setting	Conveyance	Point of entry	Route of travel	Conveyances surveyed (n)	Total detected (n)	Seasonality
Whitfield (1984)	Case series	United Kingdom	Aircraft	Gatwick Airport (London)	West Africa	Curtis and White (1984): 67	Curtis and White (1984): NS	NS
Whittingham (1938)	Review	United Kingdom	Aircraft	Findlay (1938): Malakal district in Southern Sudan*, Mozambique, Durban (South Africa*), Karachi	India*, the Iraq* , Africa, South America, Central Europe, and Russia* to United Kingdom	NS	NS	NS
Air and marine conveyances								
De Tavel (1967)	Review	International context	Aircraft and ship	Aircraft: Pacific area and Latin America Ship: Ceylan*	Aircraft: international flights to India; Pacific area and Latin America to USA Ship: docked in Ceylan*	Aircraft: flights to India (9382), Flights to USA (~400,000) Ship: NS	Aircraft: flights to India (0 *A. aegypti*), flights to USA (2.5–2.9% had mosquitoes) Ship: NS	Aircraft: flights to India (1963), flights to USA (1948) Ship: Sri Lanka (1954)
Derraik (2004)	Review	New Zealand	Aircraft and ship	Auckland, Tauranga, Lyttleton, Russell, Dunedin, Christchurch (New Zealand)	Several international flights to New Zealand	At least 171	NS	1929–2004
Iyaloo (2023)	Surveillance	Mauritius	Aircraft and ship (livestock)	Port Louis (marine), Plaine Magniene Airport (air), and animal assembly points (Mauritius)	Various flights from Asia and Africa to Mauritius	48	8428	Oct 2021–Sep 2023
Joyce (1961)	Review	USA (Hawaii)	Aircraft	Honolulu International Airport	Various international flights to Hawaii (USA)	2341	267 (8 alive, 1 knockdown)	NS
Lewis (1943)	Review	Eritrea	Ships (dhows), aircraft	The Anglo-Egyptian Sudan*	Asmara to the Anglo-Egyptian Sudan*	NS	NS	31 Mar–15 May 1942

Author (year)	Study design	Country setting	Conveyance	Point of entry	Route of travel	Conveyances surveyed (n)	Total detected (n)	Seasonality
WHO (1955)	Review	NS	Aircraft Shelley (personal communication): aircraft, ship	Shute (1952): North Africa to West Africa Symes (1948): the French Sudan* and Tanganyika*to Kisumu and Nairobi (Kenya) Hicks and Chand (1936): Karachi (Pakistan) to Amsterdam Sice, Sautet and Ethes (1939): Mali Miller (1947): Miami, Florida (USA) Shelley (personal communication): Cyprus	Shute (1952): England* Miller (1947): Africa Shelley (personal communication): aircraft (Lebanon), ship (Portugal)	NS	Shelley (personal communication): aircraft (1), ship (3)	Shute: NS Miller (1947): 1944–1945 Shelley (personal communication): 1950
Marine conveyances								
Charles (1953)	Surveillance report	British Guiana*	Ship	Georgetown, Guyana	Barbados, Saint Vincent*, Grenada, Saint Lucia, Trinidad*, and Grenadines* to Guyana	624	NS	1948–1951
Craven (1988)	Surveillance report	USA	Ship	Seattle, San Francisco, Long Beach, Chesapeake, Longview (USA)	Japan; Republic of Korea; India; Suriname; Taiwan, China; Indonesia; Hong Kong SAR, China; Sri Lanka; Singapore to various US states	NS	ND	1948–1951
Laird (1948)	Review	Graham (1939): New Zealand	Graham (1939): ship	Graham (1939): New Zealand	Graham (1939): Samarang (Indonesia), and Singapore to New Zealand	Graham (1939): NS	Graham (1939): NS	Graham (1939): NS
Laird (1994)	Surveillance report	New Zealand	Cargo ship	Auckland, New Zealand	Japan, and Australia to New Zealand	6	5	Nov–Jan
Lewis (1947)	Surveillance report	Sudan	Ship (steamer)	Sadd area of the Anglo-Egyptian Sudan*	Docked at Sadd area of the Anglo-Egyptian Sudan*	2	78	NS
Linthicum (2003)	Surveillance report	USA	Cargo ship	Ports of Los Angeles and Long Beach (USA)	China to California (USA)	15	NS	Jun 2001–Oct 2002
Moore (1988)	Surveillance report	USA	Cargo ship	Seattle, Washington (1986) and Oakland, California (1987) (USA)	1986: Japan 1987: Hawaii (USA)	1986: 9 in October, rest NS 1987: NS	0 (larva detected only)	Summers of 1986, 1987
Sinitsyn (1969)	Case report	Cuba	Commercial ship	Cuban maritime port of Cardenas	Black Sea to Cuba	1	NS	NS

Author (year)	Study design	Country setting	Conveyance	Point of entry	Route of travel	Conveyances surveyed (n)	Total detected (n)	Seasonality
Sinti-Hesse (2019)	Surveillance	Peru	River boat	Peru	Iquitos to Caballococha, Santa Rosa, and El Estrecho (Peru)	12	282 (may contain larval data)	Sep–Nov 2016; May–Jul 2017
Other conveyances								
Doughty (2020)	Surveillance report	USA	Apollo rocket and STS-41-D Discovery (space shuttles)	USA	Space round trip	2	2	NS
Edwards (1949)	Surveillance report	The Anglo-Egyptian Sudan*	Ships (dhows), trains, and aircraft	Port Sudan*	Ships: Asab*, Djibouti* or Berbera* to Sudan* Trains: Kassala Aircraft: Abyssinia and Eritrea to Egypt*	NS	Ships: 0 Trains: NS Aircraft: NS	Nov–Jan

ND = no data reported; NS = not specified.

*The geographical names mentioned in Table 5A were used in the studies cited in the first column providing the author name and year of each study, and have not been edited. These geographical names include historical names, which may not necessarily correspond to current WHO Member State names. The geographical names used in Table 5A, including historical names, are not warranted to be error-free nor do they imply official endorsement or acceptance on the part of WHO.

Table 5B. Characteristics of included empirical studies of mosquitoes carried by international conveyances [continuation]

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Air conveyances			
Carneiro de Mendonca (1947)	Novel detection: *Anopheles gambiae*, *Anopheles apicimacula*, *A. crucians*, *A. intermedius*, *A. albitarsis*	ND	**Operational efficiencies.** The change from the mixture to aerosol bombs facilitated the process, making it more efficient and effective. **User acceptability.** Initial resistance from military personnel, but eventually accepted. **Public health and health care systems.** The intervention was crucial in preventing the reintroduction of *Anopheles gambiae* and other pests into Brazil. **Political or sociocultural outcome.** Intervention involved cooperation between Brazilian and American authorities.
Cimerman (1997)	Novel detection: *Anopheles gambiae (4)*	ND	ND
Danis (1996)	NS	ND	ND
Dethier (1945)	*Anopheles gambiae*	Top of descent spraying. All mosquitoes collected on disinsected flights were found to be “invariably dead or dying”.	ND
Duguet (1949)	NS	ND	ND

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Evans (1963)	New Orleans: endemic (Culicidae (2), *Aedes* spp. (4), *Aedes sollicitans* (1), *Anopheles quadrimaculatus* Say (2), *Culex* spp. (16), *Culex nigripalpus* Theob. (1), *Culex pipens-quinquefasciatus* (22), *Culex restuans* Theob. (5), *Culex salinarius* Coq. (4), *Culex tarsalis* Coq. (15), *Mansonia perturbans* (1), *Psorophora* sp. prob. *confinnis* (L.Arr.) (4), *Psorophora confinnis* (L.Arr.) (2), *Aedes vexans* (1)) Honolulu: endemic (*Culex pipens-quinquefasciatus* (5); novel (*Aedes* sp. (1), *Aedes nigripes* (Zett.) (1), *Aedes sollicitans* (Walker) (3), *Culex* sp. (2), *Culex sitiens* Wied. (3), *Culex tritaeniorhynchus* Giles (3), *Mansonia uniformis* Theob. (11), *Anopheles annularis* Van der Wulp (1), *Anopheles nigerrimus* Giles (1), *Culex annulirostris* Skuse (1)) Miami: *Mansonia* spp. (2), *Mansonia indubitans* (Dyar and Shan) (3), *Psorophora confinnis* (5), *Aedeomyia squamipennis* L.Arr. (1), *Aedes* spp. (7), *Aedes* sp. prob. *euplocamis* (1), *Aedes albifasciatus* (Macquart) (12), *Aedes sollicitans* (Walker) (1), *Aedes taeniorhynchus* (4), *Anopheles* (*Nyssorhynchus*) spp. (1), *Culex* spp. (15), *Culex* sp. prob. *nigripalpus* Theob. (15), *Culex* sp. prob. *nigripalpus* Theob. (2), *Culex* sp. prob. *tarsalis* Coq. (1), *Culex nigripalpus* Theob. (16), *Culex tarsalis* Coq. (10), *Culex* (*Melanoconion*) spp. (2), *Mansonia titillans* (Walker) (11), *Psorophora* sp. prob. *confinnis* (L.Arr.) (1), *Culex pipens-quinquefasciatus* (14), *Culex* sp. prob. *pipens-quinquefasciatus* (1)	ND	ND
Farrell (1948)	Discusses detection and potential impact of *Anopheles gambiae* given this transmission route	No primary data on disinsection reported. Authors surmise that aircraft “spraying alone” is not sufficient to prevent air transmission of mosquitoes, without concomitant “environmental sanitation” at ports of exit.	ND
Goh (1995)	Endemic: *Culex quinquefasciatus*, *Culex tritaeniorhynchus*, *Aedes albopictus*, *Aedes aegypti*	82 out of 330 aircraft inspected were disinsected via blocks away prior to arrival. There was no difference in the rate of insect detection between disinsected (14/82) and non-disinsected (43/248) flights; however, this was not stratified by mosquitoes versus other insects. Live insects were found in 6.1% (5 out of 82) of disinsected aircraft; again, this was not stratified by mosquitoes versus other insects.	**Carriage of pathogens.** Female *Culex* mosquitoes were dissected to look for microfilariae; none were positive for microfilariae. **Financial.** Authors report that routine disinsection increases operational costs for health authority and airlines (no specific data listed on costs) **Operational.** Disinsection involves “tedious” waiting before disembarkation, leading to “discomfort” of passengers and crew.
Gratz (2000)	Pillai (1984): *Aedes aegypti* Ogata (1974): *Aedes aegypti*, *Aedes vexans*, *Anopheles subpictus*, *Culex gelidus*, *Culex sitiens* group Mayers (1983): *Aedes aegypti*	ND	ND

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Griffitts (1931)	Surveillance: *Aedes aegypti* (1), *Culex quinquefasciatus* (28), *Anopheles albimanus* and *Aedes taeniorhynchus* (via routine inspections post-study) Experiment: *Aedes aegypti* (trial 1: 40 released 13 recovered; trial 2: 30 released 3 recovered; trial 3: NS released 6 recovered)	ND	ND
Hedrich (2024)	No mosquitoes found	ND	ND
Highton (1970)	*Anopheles gambiae* Giles (2 males, 5 females), *Culex pipiens fatigans* Wiedemann (77 males, 360 females), *Culex pipiens* Linnaeus (12 males, 8 females), *Culex antennatus* (Becker) (2 males, 2 females), *Culex theileri* Theobald (1 male, 1 female), *Aedes hirsutus* Theobald (1 female), *Aedes lineatopennis* (Ludlow) (2 males, 2 females), *Aedes cumminsi* Theobald (1 male, 1 female), *Aedes dentatus* (Theobald) (1 male, 1 female), *Aedes sollicitans* (Walker) (1 male, 1 female), *Mansonia uniformis* (Theobald) (2 males, 5 females), *Culex univittatus* Theobald (2 males, 1 female), *Culiseta annulata* (Schrank) (1 male, 1 female)	ND	**Operational efficiencies.** Article recommends reimposing disinsection methods, as little to no disinsection of aircraft noted to be carried out, but authors assume breeding sites present around airport.

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Hughes (1949)	Novel: *Aedeomyia squamipennis* (6), *Aedes albifasciatus* (32), *Aedes fulvithorax* (1), *Aedes lineatopennis* (1), *Aedes nubilus* (1), *Aedes vigilax* (14), *Anopheles aquasalis* (1), *Anopheles darlingi* (1), *Anopheles hyrcanus nigerrimus* (1), *Anopheles litoralis* King (1), *Anopheles maculipennis astecus* (1), *Anopheles pharoensis* Theob. (1), *Anopheles strodei* (1), *Anopheles subpictus indefinitus* (2), *Culex annulirostris* Skuse (2), *Culex pleuristriatus* Theob. (1), *Culex sitiens* Wied. (33), *Mansonia amazonensis* (1), *Mansonia humeralis* (45), *Mansonia justamansonia* (1), *Mansonia perturbans* (27), *Mansonia pseudotitillans* (36), *Mansonia* (Mansonioides) (1) Endemic: *Aedes aegypti* (17), *Aedes atlanticus* D and K (8), *Aedes bimaculatus* (1), *Aedes cantator* (2), *Aedes dorsalis* (3), *Aedes infirmatus* D and K (3), *Aedes nigromaculis* (1), *Aedes scapularis* (6), *Aedes sollicitans* (84), *Aedes* spp. (110), *Aedes taeniorhynchus* (1159), *Aedes thelcter* (4), *Aedes tortilis* (4), *Aedes vexans* (2), *Anopheles albimanus* (121), *Anopheles albitarsis* (8), *Anopheles crucians* (57), *Anopheles grabhamu* (4), *Anopheles neomaculipapus* Curry (3), *Anopheles occidentalis* D and K (1), *Anopheles psedopunctipennis* (15), *Anopheles punctipennis* (1), *Anopheles punctulatus* (1), *Anopheles quadrimaculatus* (45), *Anopheles* spp. (30), *Anopheles vestitipennis* (1), *Anopheles walkeri* Theob. (1), *Culex chidesteri* Dyar (2), *Culex declarator* D and K (2), *Culex nigripalpus* Theob. (2), *Culex pilosus* D and K (1), *Culex pipiens* L (9), *Culex quinquefasciatus Say* (8137), *Culex salinarius* (74), *Culex* spp. (609), *Culex tarsalis* (118), *Culicidae* spp. (292), *Culiseta incidens* (1), *Culiseta inornata* (8), *Culiseta* spp. (3), *Deinocerites cancer* (6), *Deinocerites* spp. (2), *Mansonia indubitans* D and S (77), *Mansonia* species (83), *Mansonia titillans* (254), *Orthopodomyia* spp. (1), *Psorophora ciliata* (23), *Psorophora confinnis* (1108), *Psorophora cyanescens* (21), *Psorophora discolor* (3), *Psorophora ferox* (1), *Psorophora howardii* (2), *Psorophora johnstonii* (2), *Psorophora pygmaea* (22), *Psorophora signipennis* (1), *Psorophora* spp. (19), *Uranotaenia lowii* (9), *Uranotaenia sapphirina* (2), *Uranotaenia* spp. (1)	ND	ND
Hutchinson (2005)	Novel: *Culex quinquefasciatus*	Blocks away; authors suggest disinsection is effective based on detecting only a few mosquitoes.	ND
Karch (2001)	A. gambiae (2), *Culex quinquefasciatus* (3)	ND	ND
Laird (1951)	Novel: *Aedes aegypti* (L.), *Culex annulirostris* Sk. Endemic: *Mansonia crassipes* van der Wulp, *Aedes albolineatus* (Theo.), *Aedes tongae* Edw., *Culex fatigans* Wied., *Culex sitiens* Wied.	ND	ND
Laird (1952)	*Culex annulirostris* Sk. (1 female detected), *Mansonia crassipes* van der Wulp (1 female detected), *Aedes* spp. (2 detected)	ND	ND

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Le Maitre (1983)	Novel detection: *Anopheles albimanus* (2) Endemic: *Aedes aegypti* (2), *Aedes taeniorhynchus* (3), *Anopheles aquasalis* (2), *Culex quinquefasciatus* (28), other *Culex* spp. (13)	ND	ND
Moreland (1991)	*Culex pipiens* group	Residual treatment; authors reference that in a study of 67 planes from Africa, shortcomings in disinsection procedures were noted (shortcomings not specified), with live mosquitoes found on board some of these planes.	**Financial.** If proper disinsection procedures are not followed, treatment is carried out before passengers disembark on landing and all costs are charged to the airlines. **Public health, health systems.** Given a lack of awareness of travellers with respect to travel-related disease, a travel information centre was established at Heathrow Airport.
Năstoiu (1988)	Lomonaco (1961): *Anopheles sacharovi* WHO (1961): NS WHO (1971): NS	WHO (1961): all arriving flights at Miami (FL) were disinsected prior to mosquito surveillance. Not reported if arriving flights in the Philippines were disinsected or not prior to surveillance.	**Other.** Leger (1981) found that *Anopheles maculipennis* and *stephensi*, placed aboard a B-747 from Rio de Janeiro to Paris, survived under normal passenger conditions (5 hours at 20 degrees Celsius at an altitude of 11 000 ft in a pressurized cabin).
O'Rourke (1950) [unpublished report]	Culicid (1), other unknown species (4)	A subset of aircraft were disinsected with either "aerosol bomb" DDT (1–3%) or pyrethrins (0.4–0.6%). Authors report disinsection to be < 100% effective on the basis that live insects were found on inspection of disinsected flights; however, this was not stratified by mosquitoes versus other insects. Authors do not report whether flights with mosquitoes sampled underwent disinsection prior to sampling.	**Operational efficiencies.** Authors report difficulty in thoroughly examining planes due to time constraints and the presence of passengers, luggage and cargo. **Other.** Authors suggest disinsection be performed immediately before take-off and landing.
Pemberton (1944)	Novel: California: *Culex pipiens* (40), *Theobaldia incidens* (4), *Culex tarsalis* (2); Asia/Pacific via Pacific Islands: *Aedes vigilax*, *Culex sitiens*, *Anopheles litoralis*, *Aedes vexans* NS: *Anopheles pseudopunctipennis* (1 female), *Culex quinquefasciatus* (4)	Top of descent spraying with pyrethrum extract before each port, in addition to spraying with pyrethrum extract prior to departure at all stations where aircraft stopped. Live mosquitoes were found on aircraft that were presumably disinsected; however, no efficacy data were provided.	**Public health, health systems.** Quarantine stations established on Midway and Canton Islands, to inspect and spray all planes. Procedures carried out by entomologists. Salaries were paid by Hawaiian Sugar Planters' Association, and board, lodgings and transportation by Pan American Airways.
Russell (1984)	*Aedes aegypti*, *Aedes vigilax*, *Anopheles barbirostris*, *Anopheles maculatus*, *Anopheles sundaicus*, *Anopheles vagus*, *Culex quinquefasciatus*, *Culex sitiens*, *Mansonia* spp.	ND	ND
Russell (1987)	*Culex quinquefasciatus* (20)	ND	**Operational efficiencies.** Logistically challenging to disinsect aircraft wheel bays due to potential problem of grease and oil build-up on surfaces, limiting effectiveness of residual insecticides. Aerosol disinsection immediately prior to departure might be effective in preventing the transport of many insect types.
Scholte (2010)	Novel: *Culex quinquefasciatus* (4 females)	ND	ND
Scholte (2014)	Novel: *Culex quinquefasciatus* (9), *Culex antennatus* (2), *Aedes mcintoshi* Huang (1), seen but not caught (1)	ND	ND

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Smith (1984)	*Anopheles gambiae*, *Anopheles* and *Aedes*, *Anopheles grabhamii*, *Anopheles neomanculipalpis*, *Anopheles vestitipennis*, *Culex tarsalis*, *Anopheles subpictus*, *Culex tritaeniorhynchus*, *Culex quinquefasciatus*, *Anopheles subpictus* (1 female), *Aedes aegypti* (1 female), *Culex gelidus* (2 females), *Culex sitiens* (1 female), *Culex quinquefasciatus* (9 males, 15 females), *Culex pseudovishnui* (1 female), *Mansonia uniformis* (1 female), *Anopheles sundaicus*, *Anopheles subpictus*	ND	ND
Sukeriho (2013)	Novel detection: *Aedes aegypti* (1 male)	ND	**Carriage of pathogens.** Adult *Aedes* mosquitoes were examined for flavivirus and chikungunya viral genes; all were negative.
Takahashi (1984)	Novel: *Anopheles indefinitus*, *Anopheles subpictus*, *Anopheles vagus limosus*, *Mansonia annulifera*, *Aedes aegypti*, *Aedes sollicitans*, *Aedes vexans vexans*, *Culex gelidus*, *Culex vishnui* Endemic: *Culex tritaeniorhynchus*, *Mansonia uniforms*, *Anopheles sinensis*, *Aedes aegypti* (L.), *Culex pipens* L.	ND	ND
Thellier (2001)	ND: cabin mechanic bitten on airplane contracting malaria	ND	**Public health, health systems.** The case highlights a potential security issue regarding transfusion-transmitted malaria due to airport-acquired infection.
Welch (1939)	*Aedes taeniorhynchus* (1 alive, 6 dead), *Culex quinquefasciatus* (3 alive, 6 dead), *Culex* sp. (6), *Mansonia titillans* (1 dead), *Mansonia indubitans* (1 alive, 18 dead), *Mansonia* sp. (1 dead), *Anopheles albimanus* (1 dead), unidentified (1 dead)	Top of descent spraying with pyrethrum extracts (pyrethrins 2 g/100 cc mixed with mineral oil). Additionally, planes were disinsected following passenger disembarkation on all overnight stops. Live mosquitoes were found on aircraft that were presumably disinsected; however, no efficacy data were provided.	ND
Whitfield (1939)	James (1934): NS Public Health Service at Miami (1936): NS	ND	ND
Whitfield (1984)	Curtis and White (1984): Culicine mosquitoes; *Culex* spp.	ND	**Insecticide resistance.** Curtis and White (1984) report that culicine mosquitoes found on aircraft were “pyrethroid-susceptible”. **User acceptability.** The article mentions passenger reactions to insecticides as a problem in the implementation of disinsection protocols.
Whittingham (1938)	Findlay (1938): Novel (*Aedes aegypti*)	ND	ND

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Air and marine conveyances			
De Tavel (1967)	Aircraft: NS Ship: NS	Blocks away disinsection using the WHO standard reference aerosol was found to be biologically effective. The automatic dichlorvos dispenser disinsection method proved successful after practical tests were conducted on regular flights on Pan American Airways between South and Central America and Miami, Florida (USA). Routine inspection of ships (larger vessels) and routine treatment for smaller vessels (carrying 25 tons or less) was recommended. Disinsection formulation and method was not specified as well as efficacy reported.	**Tolerability.** dichlorvos spares irritation to eyes and air passages. **Operational.** Committee recognizes that disinsection of ships may impede flow of traffic. Blocks away method of aircraft disinsection causes the least travel delay. Routine treatment of ships arriving from "infested areas" may impede flow of traffic. Recommend that ships arriving in ports declared "free from insect vectors" be replaced by routine inspection. Authors also postulate that routine disinsection of ships may reduce delays caused by health procedures upon arrival.
Derraik (2004)	Endemic detection: aircraft (*Aedes* spp., *Culex* spp., *Culex* spp. (*pipiens* or *pervigilans*), *Culex* spp. (*pipiens* or *quinquefasciatus*), *Culex* (*Culex*) *quinquefasciatus* Say, many of unidentified genus); ship (*Culex* spp., *Culex* (*Culex*) *quinquefasciatus* Say, *Ochlerotatus* spp., *Ochlerotatus* (*Finlaya*) *notoscriptus* (Skuse), some of unidentified genus) Novel detection: aircraft (*Aedes* (*Scutomyia*) *albolineatus* (Theobald), *Aedes* (*Stegomyia*) *aegypti* (Linnaeus), *Aedes* (*Stegomyia*) *scutellaris* (Walker), *Aedes* (*Stegomyia*) *tongae* Edwards, *Anopheles* spp., *Anopheles* (*Anopheles*) stigmaticus Skuse, *Coquillettidia* (*Coquillettidia*) *crassipes* (Van der Wulp), *Coquillettidia* (*Coquillettidia*) *xanthogaster* (Edwards), *Culex* (*Culex*) *bitaeniorhynchus* Giles, *Culex* (*Culex*) *sitiens* Wiedemann, *Culex* (*Neoculex*) spp., *Ochlerotatus* (*Ochlerotatus*) *vigilax* (Skuse), *Ochlerotatus* (*Ochlerotatus*) *vittiger* (Skuse), *Verrallina* (*Verrallina*) *lineata* (Taylor)); ship (*Aedes* (*Stegomyia*) spp., *Aedes* (*Stegomyia*) *aegypti* (Linnaeus), *Aedes* (*Stegomyia*) *albopictus* (Skuse), *Aedes* (*Stegomyia*) *polynesiensis* Marks, *Anopheles* spp., *Anopheles* (*Anopheles*) *maculipennis* Meigen, *Culex* (*Culex*) *annulirostris* Skuse, *Culex* (*Culex*) *australicus* Dobrotworsky and Drummond, *Culex* (*Culex*) *sitiens* Wiedemann, *Culex* (*Lutzia*) *halifaxii* Theobald, *Ochlerotatus* (*Finlaya*) *japonicus* (Theobald), *Toxorhynchites* sp., *Tripteroides* (*Polylepidom* yia) *tasmaniensis* (Strickland), *Tripteroides* (*Tripteroides*) *bambusa* (Yamada))	Authors suggest that disinsection seemed to be working since the number of mosquito interceptions on aircraft and ships decreased over the course of 15 years. No primary data available.	**Public health systems, port authority.** Authors report that the sea container pathway of mosquito importation is the least well controlled of all ports of entry in New Zealand. Recent survey of container door inspections revealed 96% of invasive insects and spiders were not detected under standard protocols. **Financial.** Study reports that the government of New Zealand plans to spend approximately US$ 20 million over 4 years to eradicate *Oc. camptorhynchus*. They surmise that it would be cheaper to eradicate mosquitoes at borders rather than once populations are established on the island.
Iyaloo (2023)	*Aedes albopictus*, *Anopheles arabiensis*, *Anopheles coustani*, *Anopheles merus*, *Culex quinquefasciatus*, *Culex thalassius*, *Lutzia tigripes*	ND	**Political or sociocultural.** Authors mention use of One Health approach, discuss regional collaboration among countries in the Indian Ocean region to enhance vector surveillance and response.

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Joyce (1961)	Most common: *Culex pipiens quinquefasciatus* (113), *Culex whitmorei* (65), *Anopheles subpictus indefinitus* (39), *Culex annulirostris* Skuse (21), *Aedes vexans nocturnus* (Theob.) (16), *Aedes vexans vexans* (Meigen) (14), *Culex sitiens* Wiedemann (8), *Aedes lineatopennis* (Ludlow) (7), *Aedes dorsalis* (Meigen) (6), *Culex tritaeniorhynchus summorosus* Dyar (6), *Mansonia uniformis* (Theobald) (5) Other: *Anopheles annularis* Van der Wulp, *Anopheles annulipes* Walker, *Anopheles barbirostris* Van der Wulp, *Anopheles* sp. near *barbirostris* ?, *Anopheles freeborni* Aitken, *Anopheles litoralis* King, *Anopheles* sp. near *minimus* Theobald, *Anopheles nigerrimus* Giles, *Anopheles occidentals* Dyar and Knab, *Anopheles peditaeniatus* (Leicester), *Anopheles pseudopunctipennis* Theobald, *Anopheles punctulatus* Donitz, *Anopheles sinensis* Wiedemann, *Anopheles subpictus indefinitus* (Ludlow), *Anopheles subpictus subpictus* Grassi, *Anopheles umbrosus* (Theobald), *Aedes albopictus* (Skuse), *Aedes dorsalis* (Meigen), *Aedes lineatopennis* (Ludlow), *Aedes pampangensis* (Ludlow), *Aedes* sp. near *pandani* Stone, *Aedes polynesiensis* Marks, *Aedes sollkitans* (Walker), *Aedes squamiger* (Coquillett), *Aedes sticticus* (Meigen), *Aedes* sp. near *sticticus* (Meigen), *Aedes taeniorhynchus* (Wiedemann), *Aedes vexans vexans* (Meigen), *Aedes vexans nocturnus* (Theobald), *Aedes vexans nipponii* (Theobald), *Aedes vigilax* (Skuse), *Culex annulirostris* Skuse, *Culex* sp. near *annulirostris*, *Culex* sp. near *brevipalpis* (Giles), *Culex fuscocephalus* Theobald, *Culex peus* Speiser, *Culex pipiens pipiens* Linnaeus, *Culex pipiens quinquefasciatus* Say, *Culex sitiens* Wiedemann, *Culex tarsalis* Coquillett, *Culex tritaeniorhynchus summorosus* Dyar, *Culex whitmorei* (Giles), *Culex* sp. near *whitmorei*, *Culex* sp. near *sitiens* Wiedemann, *Aedeomyia catasticta* Knab, *Culiseta incidens* (Thomson), *Culiseta inornata* (Williston), *Culiseta* sp., *Psoropbora signipennis* (Coquillett), *Mansonia crassipes* (Van der Wulp), *Mansonia dives* (Schiner), *Mansonia uniformis* (Theobald), *Mansonia* spp. near *uniformis*, *Mansonia* (*Coquillettidia*) spp.?, *Mansonia* (*Mansonioides*) spp.?	Authors report that application of recommended aerosols at a minimum dose of 5 g/1000 ft^3 for 3 minutes is required to sufficiently kill mosquitoes. All foreign arrivals also require a secondary disinsection at the port of arrival after passengers disembark for agricultural insects. The authors report that no mosquitoes have survived this heavier aerosol dosage of 30 g/1000 ft^3.	ND
Lewis (1943)	*Aedes aegypti var. queenslandensis*, *Theobaldia* (*Allotheobaldia*) *longiareola*, *C. fatigans*	ND	ND
WHO (1955)	Shute (1952): *Anopheles* Symes (1948): *Anopheles*, *Culex* Hicks and Chand (1936): *Stegomyia*, female Sice, Sautet and Ethes (1939): *Anopheles gambiae* Miller (1947): *Anopheles pharoensis* Shelley (personal communication): aircraft (*Anopheles*), ship: (*Anopheles*)	ND	ND

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Marine conveyances			
Charles (1953)	Endemic: *Aedes aegypti* (44 foci)	Routine DDT spraying was conducted in Georgetown, including the port of Georgetown. This led to less infestation of *Aedes aegypti*. Mosquitoes were detected after effective control measures were conducted in Georgetown. To prevent reinfestation, the Mosquito Control Service conducted residual DDT spraying, fore and aft, of positive schooners, routine biannual spraying of all schooners, and annual residual DDT of premises in the dock area.	ND
Craven (1988)	Adult mosquitoes not detected; only larva	ND	ND
Laird (1948)	Graham (1939): *Anopheles maculipennis* (females)	ND	ND
Laird (1994)	Novel detection: *Aedes albopictus* (4), *Aedes japonicus* (1)	Permethrin was sprayed on shipments from Japan. Inspection yielded a dead adult *Aedes albopictus* female.	**Operational efficiencies.** The need for permethrin spraying and monitoring increased the workload of Ministry of Agriculture and Forestry inspectors.
Lewis (1947)	NS	ND	ND
Linthicum (2003)	*Aedes albopictus*	Most Dracaena maritime shipments arriving in California were treated with Scourge (resmethrin). All infestation sites were also treated with Scourge for adult mosquito control. More than 200 maritime cargo containers from Asia were treated with insecticide before they were opened and inspected. Despite adulticide efforts, large numbers of *Aedes albopictus* were detected at infestation sites. Multiple *Aedes albopictus* mosquitoes were also observed flying out of the containers and biting staff. An embargo of shipments of Dracaena in standing water was enacted. Dry shipments were still treated with Scourge upon arrival before they were opened and inspected. Mosquito outbreaks at nurseries only resolved with embargo of shipments, rather than just disinsection of shipping containers.	**Carriage of pathogens.** 21 *Aedes* mosquitoes were tested for dengue, Japanese encephalitis, Murray Valley encephalitis, and Saint Louis encephalitis viruses; all were negative.

Author (year)	Species (n)	Disinsection formulation, method and efficacy	Other outcomes
Moore (1988)	ND	ND	**Insecticide resistance.** Insecticide susceptibility testing on *Aedes albopictus* showed increased resistance to bendiocarb, malathion and temphos. **Legal.** Interception of *Aedes albopictus* in shipments of used tyres led to the implementation of Public Law 78-410, Public Health Service Act, Section 361, and 42 CFR 71.32(c)(10), where the CDC required used tyre casings from Asia to be certified as dry, clean and free of insects.
Sinitsyn (1969)	"Massive mosquito attack"	ND	ND
Sinti-Hesse (2019)	*Aedes aegypti* (1), *Aedeomiya* (27), *Anopheles nuneztovari* (2), *Anopheles peryasui* (0), *Anopheles trianulatus* (1), *Coquillettidia* (3), *Culex melanoconium* (1), *Culex* spp. (36), *Mansonia* spp. (211)	ND	ND
Other conveyances			
Doughty (2020)	Super Florida mosquito *Psorophora ciliata* (1), unknown mosquito (1)	ND	ND
Edwards (1949)	Ships: NS Trains: *Anopheles* Aircraft: *Culex fatigans* and *Culiseta longiareolata* Other: *Anopheles dthali*, *Anopheles turkhudi*, *Anopheles multicolor*, *Anopheles gambiae*, *Aedes aegypti var. queenslandensis*, *Culex sitiens*, *Culex sinaiticus* (origin NS)	**Aircraft.** Aircraft arriving from the south, specifically Ethiopia (formerly Abyssinia) and Eritrea, were disinsected and inspected immediately on arrival. Flights from Asmara (Eritrea) coming to Sudan were sprayed before departure, which was able to eliminate mosquitoes on the planes. If planes were delayed at Port Sudan for more than an hour or made an overnight stay, they were sprayed before departure. **Boats and ships (dhows).** All dhows were inspected and disinsected before leaving Port Sudan or Suakin. This was able to reduce the number of *Aedes* infections. Ships from East Africa (Asab, Djibouti or Berbera) were inspected and disinsected before release to work berths. **Trains.** Trains from Kassala, arriving at Sinkat station, were sprayed with insecticide after *Anopheles* mosquitoes were identified. Disinsection reduced the numbers of mosquitoes considerably.	**Public health, health systems.** Quarantine (Sailing) Boats Regulations established in 1944 in response to *Aedes* infestations on dhows. Regulations ensured that no boat could leave the port without a public health clearance certificate stating the ship had been inspected and found to be mosquito free within 48 hours of departure.

ND: data not reported; NS: data not specified.

Note: Species names as reported in study regardless of present-day nomenclature (e.g., *Culex pipiens fatigans* now known as *Culex quinquefasciatus*; *Mansonia perturbans* now known as *Coquillettidia perturbans*; *Theobaldia longiareolata* now known as *Culiseta longiareolata*; *Theobaldia incidens* now known as *Culiseta incidens*; etc.).

Table 6A. Characteristics of included empirical studies of mosquitoes with potential for international conveyance identified at international points of entry

Author (year)	Study design	Country setting	Point of entry	Seasonality, surveillance period	Number of ports surveyed	Species detected (n)[a]
Airports						
Bakran-Lebl (2021)	Surveillance report	Austria	Vienna International Airport	Weekly from 13 June to 31 October 2018, and 2 May to 30 October 2019	1	Endemic: *Anopheles claviger* (2), *Anopheles hyrcanus* (1), *Anopheles maculipennis* Complex (9), *Anopheles* spp. (4), *Aedes caspius* (9), *Aedes cinereus/geminus* (9), *Aedes geniculatus* (2), *Aedes japonicus* (1), *Aedes sticticus* (81), *Aedes vexans* (452), *Aedes* spp. (126), *Culex hortensis* (1), *Culex modestus* (14), *Culex pipiens/torrentium*, *Culex territans* (1), *Culex* spp. (674), *Culiseta annulate* (15), *Culiseta longiareolata* (1), *Culiseta* spp. (10), *Coquillettidia richiardii* (6), and *Uranotaenia unguiculata* (1), as well as undefined species (4). Total (4850)
D'Ambrosio (1951)	Surveillance report	Italy	Airports in Chinisia, Castelvetrano, Milo, Trapani, Marsala	June 1947 to November 1950	5	*Anopheles* (*Maculipennia*) *labranchiae* Fni. (718), *Anopheles claviger* Meig. (333). Total (1051)
Furumizo (2005)	Surveillance report	USA[9] (Hawaii)	Honolulu International Airport	8 December 2003	1	Novel detection: *Anopheles* (*Anopheles*) *punctipennis* (Say). Total (1)
Guillet (1998)	Surveillance report	Senegal, Benin, Côte d'Ivoire and Cameroon	Airports in Senegal, Benin, Côte d'Ivoire and Cameroon	July to September 1995	4	*Anopheles arabiensis*, *Anopheles pharoensis*, *Culex quinquefasciatus*, *Anopheles gambiae* s.s., *Anopheles gambiae* s.l., *Anopheles moucheti*, and *Anopheles funestus*. Total (3383)
Ibanez-Justicia (2017)	Surveillance report	Netherlands (Kingdom of the)	Schiphol International Airport	Sampling was done from June to October 2016	1	Endemic: *Anopheles maculipennis* (*sensu lato*) (17), *Culiseta annulata* (15), *Culex pipiens/torrentium* (1316), and *Aedes aegypti* (6). Total (1354)
Laird (1956)	Review	Singapore	Paya Lebar International Airport	March to August 1954; February to April 1955; and July 1955	1	*Aedes albopictus*, *Aedes aegypti*, and *Culex pipiens fatigans*. Total (ND)
Larish (2005)	Surveillance report	USA (Hawaii)	Hilo and Waimea Airports	November 2003 and June to December 2004	NA	Novel detection: *Aedes* (*Finlaya*) *japonicus japonicus* (Theobald). Total (29)
Macdonald (1956)	Surveillance report	Malaysia	Kuala Lumpur Airport	ND	1	*Aedes albopictus* (6), *Aedes lineatopennis* (5), *Aedes vexans* (1), *Aedomyia venustipes* (4), *Culex fatigans* (242), *Culex gelidus* (8), *Culex bitaeniorhynchus* (1), *Culex vishnui* spp. 'a' (30), *Culex vishnui* spp. 'b' (31), *Culex tritaeniorhynchus* (12), *Culex fuscanus* (1), *Culex nigropunctatus* (4), *Mansonia uniformis* (31), *Mansonia annulifera* (2), *Anopheles hyrcanus* (49), *Anopheles karwari* (1), *Anopheles aconitus* (1), and *Anopheles philippinensis* (2). Total (435)

[9] United States of America

Author (year)	Study design	Country setting	Point of entry	Seasonality, surveillance period	Number of ports surveyed	Species detected (n)[a]
Macdonald (1958)	Surveillance report	Malaysia	Kuala Lumpur International Airport	September 1955 to March 1956	1	*Culex*, *Mansonia*, *Anopheles*, and *Aedes albopictus*. Total (1054)[b]
Ong (2018)	Experimental trial	Australia	Australian international airports	April	8	Novel detection: *Aedes aegypti*. Total (79)
Sukehiro (2013)	Surveillance report	Japan	Narita International Airport	Routine surveillance: January to November 2012 Intensive surveillance: August to October 2012	1	Routine surveillance: *Culex tritaeniorhynchus* (92), *Culex pipiens* gr., (39), *Aedes vexans nipponii* (6), *Anopheles sinensis* (5), and *Armigeres subalbatus* (2). Total (144) Intensive surveillance: novel *Aedes aegypti* (27),[c] *Culex tritaeniorhynchus* (105), *Culex .pipiens* gr. (94), *Aedes albopictus* (12), *Anopheles sinensis* (2), and *Armigeres subalbatus* (2). Total (242)
Farrell (1948)	Review	Brazil	Brazilian airports	1942–1943	2	*Anopheles gambiae*. Total (ND)
Seaports						
Holder (2010)	Surveillance report	New Zealand	Port of Auckland	Early March 2007 to mid-May 2007	1	*Culex* spp. and *Aedes* spp. Total (155)[b]
Lokossou (2023)	Surveillance report	Benin	Port Autonome de Cotonou	May to August 2022	1	*Anopheles gambiae*, *Anopheles pharoensis*, *Culex quinquefasciatus*, *Mansonia africana*, *Mansonia uniformis*, and *Aedes aegypti*. Total (349)[d]
Wilke (2022)	Surveillance report	USA	Maritime ports of entry in Miami-Dade County	Spring (6 weeks) from April to May 2021 and summer (6 weeks) from June to July 2021	12	*Aedes aegypti* (11 247), *Aedes albopictus* (123), *Aedes bahamensis* (135), *Aedes taeniorhynchus* (136), *Aedes tortilis* (883), *Anopheles atropos* (1), *Anopheles quadrimaculatus* (4), *Culex coronator* (17), *Culex erraticus* (1), *Culex nigripalpus* (11), *Culex quinquefasciatus* (19 986), and *Deinocerites cancer* (45). Total (32 589)
***Airports and seaport*s**						
Deblauwe (2017)	Surveillance report	Belgium	Ports in Belgium	2012–2016	35	*Aedes albopictus*. Total (ND)
Murphy (2012)	Surveillance report	United Kingdom[10]	London Heathrow Airport, London Gatwick Airport, Southampton seaport, Felixstowe seaport, Liverpool seaport, Manchester seaport, Hull seaport, Bristol seaport, Belfast City Airport, Belfast seaport, and Belfast International Airport	Summer 2009 and 2010	11	*Culex pipiens* s.l., *Culiseta annulata*, *Anopheles maculipennis* s.l., *Anopheles claviger*, *Ochlerotatus detritus*, and *Coquillettidia richiardii*. Total (ND)
De Tavel (1976)	Review	International context	Several port cities of the Caribbean area	ND	ND	*Aedes aegypti*. Total (ND)

[10] United Kingdom of Great Britain and Northern Ireland

Author (year)	Study design	Country setting	Point of entry	Seasonality, surveillance period	Number of ports surveyed	Species detected (n)[a]
Schmidt (2020)	Surveillance report	Australia	Airport in Sydney, Airport in Melbourne, seaports in Darwin and Brisbane	4 April 2016 to 17 December 2018	20	*Aedes albopictus*. Total (ND)
Vasquez (2023)	Surveillance report	Cyprus	Airport and seaport in Larnaka and marina and old port of Limassol ports	May–July 2022 and September–October 2022	4	*Aedes albopictus* (51), *Aedes aegypti* (5), *Aedes caspius* (22), *Aedes detritus* (165), *Culex pipiens* (195), *Culiseta longioreolata* (6), and *Culex* spp. (14). Total (458)
Vaux (2011)	Surveillance report	United Kingdom	Belfast City Airport, Belfast port, Belfast International Airport, Bristol port, Felixstowe port, Hull port, Liverpool port, London Gatwick Airport, London Heathrow Airport, Manchester port, Southampton port	2009–2010: traps were set from April to October	11	Endemic: *Culex pipiens* s.1., *Anopheles maculipennis* s.l., *Culiseta annulata*, *Coquilletidia richiardii*, *Anopheles claviger*, and *Ochlerotatus detritus*. Total (ND)
Airports, seaports, and highways						
Scholte (2007)	Review	Albania, Italy, France, Belgium, Montenegro, Switzerland, Greece, Spain, Croatia, Netherlands (Kingdom of the), Slovenia, and Bosnia and Herzegovina	Ports in Albania, Italy, France, Belgium, Montenegro, Switzerland, Greece, Spain, Croatia, Netherlands (Kingdom of the), Slovenia, and Bosnia and Herzegovina	ND	ND	*Aedes albopictus*. Total (ND)
Railway						
Becker (2017)	Surveillance report	Germany	Railway station in Freiburg	July to October 2015	1	*Aedes albopictus*. Total (4043)
Reports of airport malaria with credible conveyance or airport transmission						
Giacomini (1995)	Case series	France	Roissy Charles-de Gaulle Airport	July to August	1	NR Total (6)[e] *Plasmodium falciparum*[f]
Giacomini (1998)	Review	France, Belgium, Switzerland, United Kingdom, Italy, Netherlands (Kingdom of the), Germany, and Spain	NR	The cases occurred during very hot summers	NR	NR Total (66)[e] *Plasmodium falciparum*,[f] *Plasmodium vivax*,[e] *Plasmodium malaria*,[f] *Plasmodium ovale*,[f] and *Plasmodium falciparum + ovale*[f]

Author (year)	Study design	Country setting	Point of entry	Seasonality, surveillance period	Number of ports surveyed	Species detected (n)[a]
Guillet (1998)	Review	France, Belgium, Italy, Netherlands (Kingdom of the), Spain, Switzerland, and United Kingdom	NR	NR	NR	NR Total (63)[e] *Plasmodium falciparum*,[f] *Plasmodium malariae*,[f] and *Plasmodium vivax*.[f]
Van den Ende (1995)	Case report	Belgium	International Airport of Brussels	All cases occurred in August 1995 during an exceptionally hot period	1	NR Total (6)[e] *Plasmodium falciparum*[f] and *Plasmodium ovale*[f,e]
Other						
O'Neill (2009)	Surveillance report	Russian Federation	International Space Station	18 months	1	Likely *Aedes aegypti* or *Anopheles gambiae*. Total (1)
The Day: Local News (2019)	Surveillance report	USA	Naval submarine base	August	1	NR Total (ND)

NA = not applicable; ND = no data; NR = not reported.

a. Number of mosquitoes for each species reported when data were available.

b. Estimates of adults collected were made using the figure in full text.

c. Adult *Aedes aegypti emerged from larvitraps set in August 2012.*

d. Culex spp. (endemic) and Aedes spp. novel.

e. Number of reported cases of airport malaria.

f. Species of Plasmodium parasite reported in malaria infections.

Note: Species names as reported in study regardless of present-day nomenclature (e.g., *Culex pipiens fatigans* now known as *Culex quinquefasciatus*; *Mansonia perturbans* now known as *Coquillettidia perturbans*; *Theobaldia longiareolata* now known as *Culiseta longiareolata*; *Theobaldia incidens* now known as *Culiseta incidens*; etc.).

3.8 Summary of methodological quality and risk of bias assessment

Collectively, the studies of aircraft disinsection reporting mosquito mortality were of generally low quality with high risk of bias (Figure 3, Table 7). Additionally, the composite methodological quality score, as ascertained by adherence to WHO's published guidelines *(31)* for studies evaluating the efficacy of aircraft disinsection, was 33.3%, ranging from 18.2% to 60.5% (Table 3, Table 7).

Figure 3. Risk of bias assessment for studies reporting efficacy of vehicular mosquito disinsection

Similarly, studies of aircraft disinsection reporting human safety, toxicity and tolerability were of equally low quality and high risk of bias (Figure 4, Table 8), with only two human studies reporting an unexposed human comparator or control arm *(54, 55)*. Only one study *(55)* of aircraft disinsection evaluating safety or toxicity in humans adhered to standard study design or reporting of methodological rigour, including approval by institutional review boards or research ethics committees governing human subject considerations in research; description or notation of recruitment process, eligibility assessment and informed consent of participants; study protocol registration; a statement of independence of investigators from stakeholders and disclosures of funding; and collection and reporting of objective biological, behavioural or psychological metrics corroborating subjectively reported tolerability and, more notably, intolerability. Collectively, studies of human safety, toxicity or tolerability of aircraft mosquito disinsection were either at serious risk of bias for morbidity outcomes *(54, 58, 60)* or at very serious risk of bias for safety, toxicity and tolerability outcomes *(37, 52–54, 56–61)*, with estimated health effects of very low certainty according to GRADE assessment.

Figure 4. Risk of bias assessment for studies reporting the safety, toxicity and tolerability of vehicular disinsection

3.9 Quantitative and qualitative synthesis

3.9.1 Summary of findings: efficacy

A quantitative synthesis of aircraft disinsection efficacy can be found in Table 7. Collectively across comparator trials of aircraft disinsection efficacy, the odds of mosquito mortality in the experimental (exposed) arms compared to control (unexposed) arms (that is, the odds ratio) was 163.6 (95% confidence interval (CI), 147–182) and the risk of mosquito mortality in the exposed versus unexposed arms (that is, the relative risk) was 14.24 (95% CI, 12.99–15.63) (Table 7), supporting the high insecticidal efficacy of disinsection.

Credit: WHO / Yoshi Shimizu
Health workers conduct mosquito sampling and surveillance in a community in Vientiane.

Table 7. Summary of findings: efficacy outcome

Insecticide compared to control (no insecticide) during disinsection of conveyances
Population: mosquitoes
Setting: aircraft
Intervention: disinsection
Comparison: no disinsection
Outcome: mosquito mortality
Study design: experimental trial with non-exposed (control) comparator group

Stratification	No. of studies	Mortality exposed (%)	Mortality unexposed (%)	Relative risk (95% CI)	Odds ratio (95% CI)	Risk of bias	Inc.[a]	Ind.[b]	Imp.[c]	Certainty of evidence (GRADE)[d]	Overall adherence to WHO guidelines on disinsection[e]	References
Overall												
All insecticides	9	28 819/31 371 (91.9%)	421/6528 (6.5%)	14.24 (12.99–15.63)	163.6 (147–182)	Very serious	High risk	High risk	Low risk	Very low ⊕◯◯◯	33.3% (54/162)	Berger-Preiss Sullivan 1972 Sullivan 1974 Brooke Langsford Liljedhal Sullivan 1962 Sullivan 1975 Sullivan 1978
Genus of mosquito												
Aedes	6	17 649/18 437 (95.7%)	154/2804 (5.5%)	17.43 (14.96–20.33)	384 (321.6–458.4)	Serious	High risk	High risk	Low risk	Low ⊕⊕◯◯	33.2% (36.5/110)	Berger-Preiss Sullivan 1974 Sullivan 1972 Brooke Liljedhal Sullivan 1962
Anopheles	4	4461/4523 (98.6%)	69/1047 (6.6%)	14.97 (11.94–18.82)	1005 (709.2–1424)	Very serious	High risk	High risk	Low risk	Very low ⊕◯◯◯	33.3% (25/75)	Berger-Preiss Sullivan 1972 Liljedhal Sullivan 1962

Stratification	No. of studies	Mortality exposed (%)	Mortality unexposed (%)	Relative risk (95% CI)	Odds ratio (95% CI)	Risk of bias	Inc.[a]	Ind.[b]	Imp.[c]	Certainty of evidence (GRADE)[d]	Overall adherence to WHO guidelines on disinsection[e]	References
Culex	6	8004/9787 (81.8%)	20/1452 (1.4%)	59.37 (38.61–91.55)	313.6 (202.2–486.5)	Very serious	High risk	High risk	Low risk	Very low ⊕◯◯◯	34.4% (37.5/109)	Berger-Preiss Sullivan 1972 Langsford Liljedhal Sullivan 1962 Sullivan 1975
Pooled: genus	9	30 114/32 747 (92%)	243/5303 (4.6%)	20.07 (17.76–22.70)	237.6 (207.7–271.9)	Very serious	High risk	High risk	Low risk	Very low ⊕◯◯◯	33.3% (54/162)	Berger-Preiss Sullivan 1972 Sullivan 1974 Brooke Langsford Liljedhal Sullivan 1962 Sullivan 1975 Sullivan 1978
Method of disinsection												
Pre-embarkation (aerosol)	1	1595/1612 (99%)	0/237 (0%)	∞ (2–∞)	43 306 (2596–722 509)	Serious	NA	High risk	High risk	Very low[e] ⊕◯◯◯	18.2% (4/22)	Berger-Preiss
Pre-embarkation (residual)	1	5781/7309 (79.1%)	8/408 (2%)	40.34 (20.7–79.35)	178.2 (90.14–352.4)	Serious	NA	High risk	High risk	Very low[e] ⊕◯◯◯	18.2% (4/22)	Berger-Preiss
Blocks away	8	21 667/22 674 (95.6%)	235/4451 (5.3%)	18.1 (15.99–20.50)	385.1 (332.9–445.4)	Very serious	High risk	High risk	High risk	Very low ⊕◯◯◯	35.7% (50/140)	Sullivan 1972 Sullivan 1974 Brooke Langsford Liljedhal Sullivan 1962 Sullivan 1975 Sullivan 1978

Stratification	No. of studies	Mortality exposed (%)	Mortality unexposed (%)	Relative risk (95% CI)	Odds ratio (95% CI)	Risk of bias	Inc.[a]	Ind.[b]	Imp.[c]	Certainty of evidence (GRADE)[d]	Overall adherence to WHO guidelines on disinsection[e]	References
Pooled: method of disinsection	9	29 043/31 595 (91.9%)	243/5096 (4.8%)	19.28 (17.06–21.80)	226.8 (198.2–259.6)	Very serious	High risk	High risk	High risk	Very low ⊕◯◯◯	33.3% (54/162)	Berger-Preiss Sullivan 1972 Sullivan 1974 Brooke Langsford Liljedhal Sullivan 1962 Sullivan 1975 Sullivan 1978
Insecticide												
Allethrin	1	328/378 (86.8%)	2/103 (1.9%)	44.69 (12.74–162.5)	264.1 (72.75–958.7)	Very serious	NA	High risk	High risk	Very low[e] ⊕◯◯◯	36.1% (6.5/18)	Sullivan 1972
Bioresmethrin	2	4435/4570 (97.1%)	102/1057 (9.7%)	10.06 (8.381–12.11)	305.1 (233.9–398.1)	Serious	High risk	High risk	High risk	Very low[e] ⊕◯◯◯	36.8% (12.5/34)	Sullivan 1972 Brooke
DDT-containing	3	5639/6319 (89.2%)	112/1940 (5.8%)	15.46 (12.93–18.52)	134.7 (109.6–165.6)	Serious	Low risk	High risk	Low risk	Low ⊕⊕◯◯	39% (19.5/50)	Langsford Brooke Sullivan 1962
d-Phenothrin	4	12 687/14 274 (88.9%)	96/2169 (4.4%)	20.08 (16.53–24.43)	171.7 (139.1–212)	Serious	High risk	High risk	Low risk	Low ⊕⊕◯◯	27% (20.5/76)	Berger-Preiss Sullivan 1974 Sullivan 1978 Liljedhal
Pyrethrins	4	6820/7523 (90.7%)	114/2044 (5.6%)	16.25 (13.61–19.44)	163.5 (133.3–200.4)	Serious	High risk	High risk	Low risk	Low ⊕⊕◯◯	38.2% (26/68)	Sullivan 1972 Brooke Langsford Sullivan 1962
Resmethrin	3	4549/4626 (98.3%)	107/1155 (9.3%)	10.61 (8.68–12.73)	572.6 (424.3–772.6)	Very serious	Low risk	High risk	High risk	Very low ⊕◯◯◯	38.5% (20/52)	Sullivan 1972 Brooke Sullivan 1975

Stratification	No. of studies	Mortality exposed (%)	Mortality unexposed (%)	Relative risk (95% CI)	Odds ratio (95% CI)	Risk of bias	Inc.[a]	Ind.[b]	Imp.[c]	Certainty of evidence (GRADE)[d]	Overall adherence to WHO guidelines on disinsection[e]	References
Pooled: insecticide	9	28 819/31 371 (91.9%)	421/6528 (6.5%)	14.24 (12.99–15.63)	163.6 (147–182)	Very serious	High risk	High risk	Low risk	Very low ⊕◯◯◯	33.3% (54/162)	Berger-Preiss Sullivan 1972 Sullivan 1974 Brooke Langsford Liljedhal Sullivan 1962 Sullivan 1975 Sullivan 1978
Aircraft												
Airbus	1	5281/6826 (77.4%)	4/565 (0.7%)	109.3 (42.83–280.7)	426.4 (168.3–1,080)	Serious	NA	High risk	High risk	Very low[e] ⊕◯◯◯	18.2% (4/22)	Berger-Preiss
BAC	1	566/601 (94.2%)	2/148 (1.4%)	69.69 (19.65–253.6)	935.1 (256.1–3415)	Very serious	NA	High risk	High risk	Very low ⊕◯◯◯	36.1% (6.5/18)	Sullivan 1972
Boeing	5	8728/8839 (98.7%)	76/1784 (4.3%)	23.18 (18.63–28.90)	1748 (1301–2350)	Serious	High risk	High risk	High risk	Low ⊕⊕◯◯	29.3% (27/92)	Berger-Preiss Sullivan 1974 Sullivan 1972 Langsford Liljedhal
Caravelle	1	230/330 (69.7%)	0/72 (0%)	∞ (2–∞)	332.6 (20.4–5421)	Very serious	NA	High risk	High risk	Very low ⊕◯◯◯	47.2% (8.5/18)	Sullivan 1962
De Havilland	3	12 145/12 667 (95.9%)	107/1882 (5.7%)	16.86 (14.05–20.29)	383.9 (310.1–475.3)	Very serious	Low risk	High risk	Low risk	Very low ⊕◯◯◯	40.4% (21/52)	Sullivan 1972 Brooke Sullivan 1962
Lockheed	2	539/539 (100%)	28/219 (12.8%)	7.821 (5.714–9.437)	7250 (440.5–119 330)	Very serious	Low risk	High risk	High Risk	Very low ⊕◯◯◯	34.7% (12.5/36)	Sullivan 1975 Sullivan 1978
Viscount	1	1330/1569 (84.8%)	4/258 (1.6%)	54.67 (21.63–140.2)	314.2 (122.5–806.1)	Very serious	NA	High risk	High risk	Very low ⊕◯◯◯	47.2% (8.5/18)	Sullivan 1962

Stratification	No. of studies	Mortality exposed (%)	Mortality unexposed (%)	Relative risk (95% CI)	Odds ratio (95% CI)	Risk of bias	Inc.[a]	Ind.[b]	Imp.[c]	Certainty of evidence (GRADE)[d]	Overall adherence to WHO guidelines on disinsection[e]	References
Pooled: aircraft	9	28 769/31 321 (91.9%)	220/4913 (4.5%)	20.48 (18.02–23.35)	240.0 (208.5–276.2)	Very serious	High risk	High risk	Low risk	Very low ⨁◯◯◯	33.3% (54/162)	Berger-Preiss Sullivan 1972 Sullivan 1974 Brooke Langsford Liljedhal Sullivan 1962 Sullivan 1975 Sullivan 1978

CI = confidence interval; NA = not applicable.

GRADE Working Group grades of evidence: Inc: inconsistency; Ind: indirectness; Imp: imprecision.

a. Inconsistency assigned to studies due to variance in point estimates and no/minimal overlap in confidence intervals.

b. Indirectness assigned to all studies due to use of non-WHO approved insecticides, obsolete passenger aircraft, and overall non-adherence to WHO published guidelines on testing efficacy of disinsection. Only one study (Berger-Preiss et al. 2006) *(33)* used a WHO-approved insecticide and currently operational passenger aircraft model, but was considered high risk of indirectness due to poor adherence to WHO guidelines on testing disinsection (18.18%).

c. Indirectness assigned due to wide 95% confidence intervals.

d. All studies were downgraded at least one level of evidence based on inconsistency, indirectness and imprecision.

e. Percentage adherence to a formulated checklist representing WHO *Guidelines for testing the efficacy of insecticide products used in aircraft (31)*. The value listed is an aggregate average of all studies represented in each stratified line item.

Note: Pre-embarkation stratified subgroups (under Method of disinsection) and Airbus stratified subgroup (under Aircraft) were downgraded two levels of evidence based on high risk of indirectness (combination of insecticide and method tested – d-phenothrin and pre-embarkation/residual treatments – are not WHO recommended, and poor adherence to WHO disinsection testing guidelines) and imprecision (wide 95% confidence intervals). Bioresmethrin and Allethrin (under Insecticide) were also downgraded two levels of evidence given high risk in inconsistency for bioresmethrin (large variance between point estimates of studies), indirectness for both (not a WHO-approved insecticide, obsolete passenger aircraft, poor adherence to WHO disinsection testing guidelines), and imprecision for both (wide 95% confidence intervals).

Across *mosquito genera*, the odds of mosquito mortality for disinsection versus control was 237.6 (95% CI, 207.7–271.9) and relative risk was 20.07 (95% CI, 17.76–22.7) (Table 7, Figure 5). For *Aedes* species of mosquitoes, the odds of mosquito mortality for disinsection versus control was 384 (95% CI, 321.6–458.4), with relative risk of 17.43 (95% CI, 14.96–20.33) (Figure 6). For *Anopheles* species of mosquitoes, the odds of mosquito mortality for disinsection versus control was 1005 (95% CI, 709.2–1424), with relative risk of 14.97 (95% CI, 11.94–18.82) (Figure 7). For *Culex* species of mosquitoes, the odds of mosquito mortality for disinsection versus control was 313.6 (95% CI, 202.2–486.5), with relative risk of 59.37 (95% CI, 38.61–91.55) (Figure 8).

Figure 5. Forest plot of odds ratios of disinsection efficacy according to mosquito species

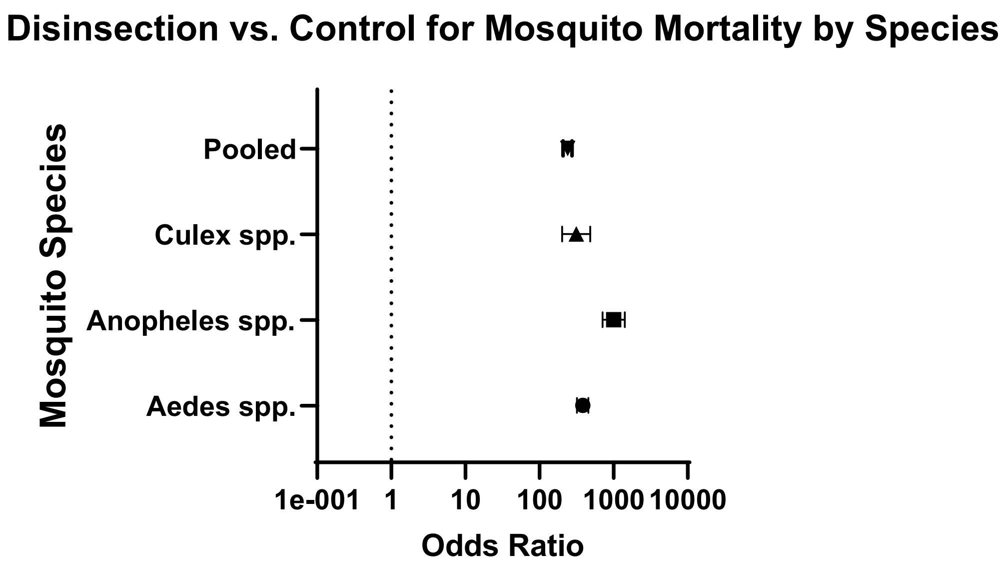


Figure 6. Forest plot of odds ratios of disinsection efficacy for *Aedes* spp. mosquitoes

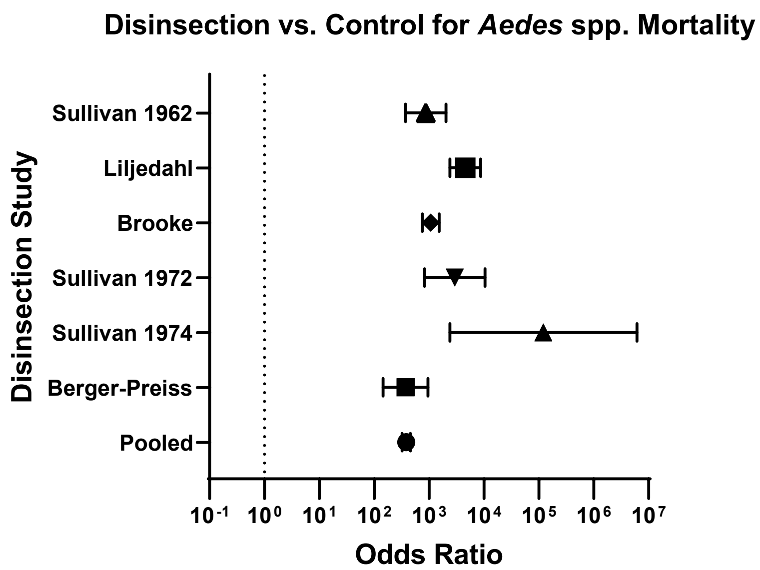


Figure 7. Forest plot of odds ratios of disinsection efficacy for *Anopheles* spp. mosquitoes

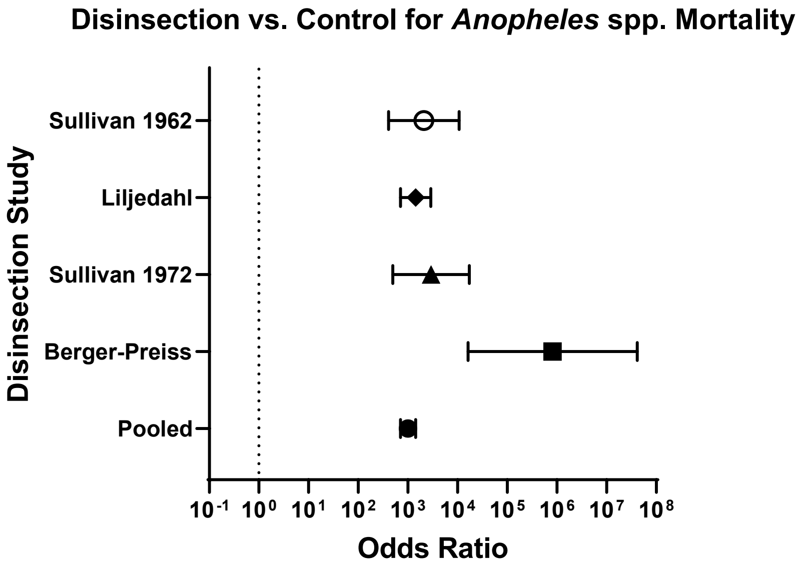
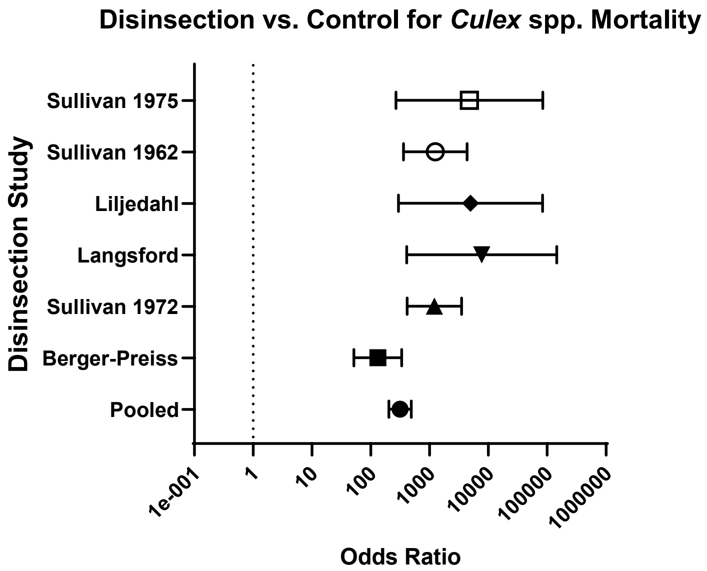


Figure 8. Forest plot of odds ratios of disinsection efficacy for *Culex* spp. mosquitoes



Across *methods of disinsection*, the odds of mosquito mortality for disinsection versus control was 226.8 (95% CI, 198.2–259.6), and relative risk was 19.28 (95% CI, 17.06-21.8) (Table 7, Figure 9). For pre-embarkation *residual* disinsection, the odds of mosquito mortality for disinsection versus control was 178.2 (95% CI, 90.14–352.4), with relative risk of 40.34 (95% CI, 20.7–79.35). For pre-embarkation *aerosol* spraying, the odds of mosquito mortality for disinsection versus control was 43 306 (95% CI, 2596–722 509), with relative risk of infinity (95% CI, 2 to infinity). For "blocks away" disinsection, the odds of mosquito mortality for disinsection versus control was 385.1 (95% CI, 332.9–445.4), with relative risk of 18.1 (95% CI, 15.99–20.5) (Figure 10). No comparator trials (that is, with an unexposed mosquito control arm) for "top of descent" spraying were identified.

Figure 9. Forest plot of odds ratios of disinsection efficacy according to method of disinsection

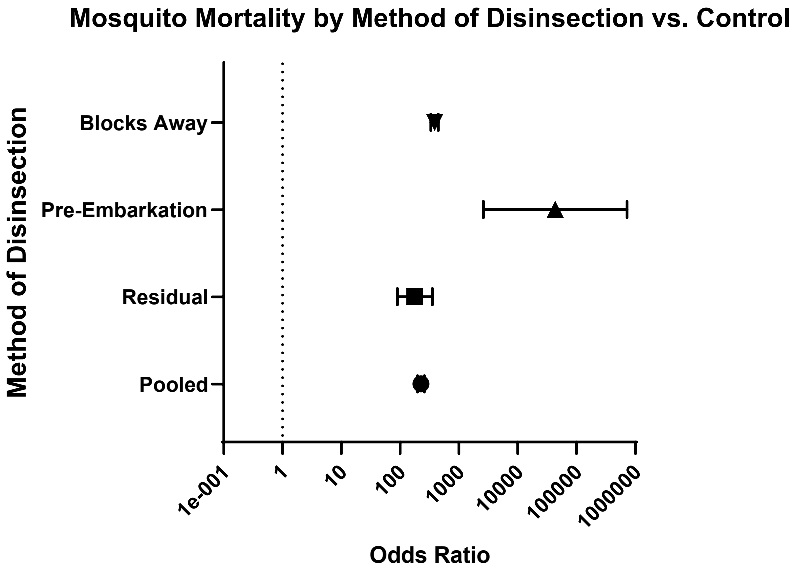
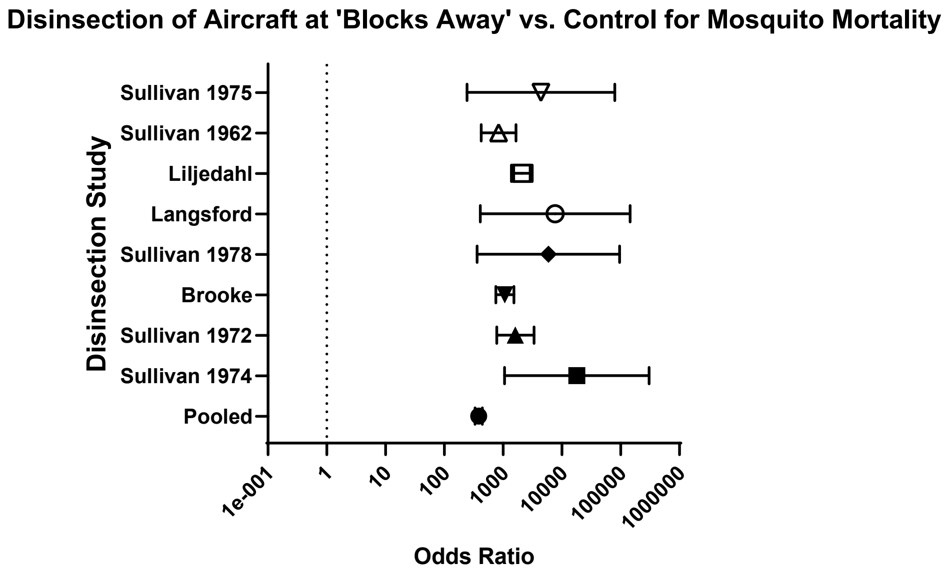


Figure 10. Forest plot of odds ratios of disinsection efficacy for "blocks away" disinsection



Across *aircraft models*, the odds of mosquito mortality for disinsection versus control was 240 (95% CI, 208.5–276.2), and the relative risk was 20.48 (95% CI, 18.02–23.31) (Table 7, Figure 11). For models of Boeing aircraft (707, 727 and 747), the odds of mosquito mortality for disinsection versus control was 1748 (95% CI, 1301–2350), with relative risk of 23.18 (95% CI, 18.63–28.9) (Figure 12). For models of Airbus aircraft (310), the odds of mosquito mortality for disinsection versus control was 426.4 (95% CI, 168.3–1080), with relative risk of 109.3 (95% CI, 42.83–280.7). For models of De Havilland aircraft (D-6, D-8 and Comet), the odds of mosquito mortality for disinsection versus control was 383.9 (95% CI, 310.1–475.3), with relative risk of 16.86 (95% CI, 14.05–20.29) (Figure 13). For models of Lockheed aircraft, the odds of mosquito mortality for disinsection versus control was 7250 (95% CI, 440.5–119 330), with relative risk of 7.821 (95% CI, 5.714–9.437) (Figure 14). Odds ratios and relative risks for mosquito mortality in BAC, Vickers Viscount and Sud Caravelle models of aircraft are as noted in the efficacy summary of findings table and all-aircraft forest plot (Table 7, Figure 11).

Figure 11. Forest plot of odds ratios of disinsection efficacy according to make of aircraft

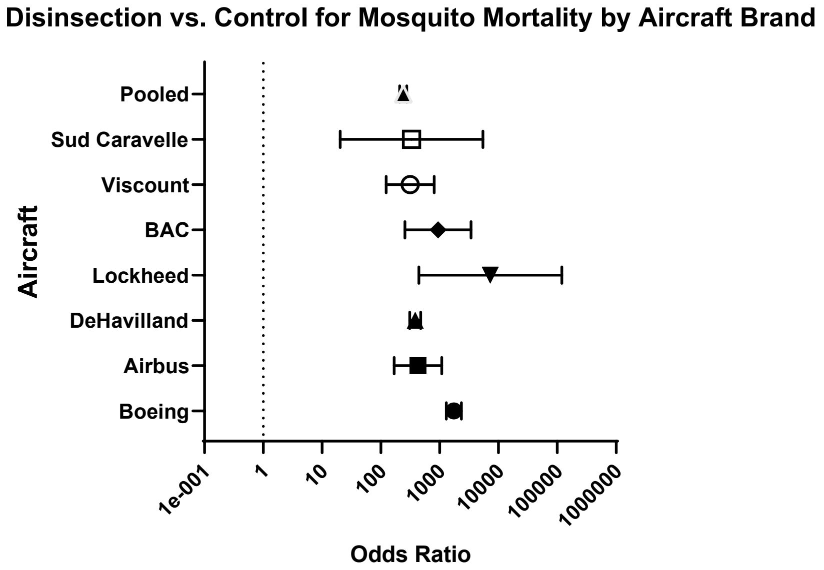


Figure 12. Forest plot of odds ratios of disinsection efficacy for Boeing aircraft

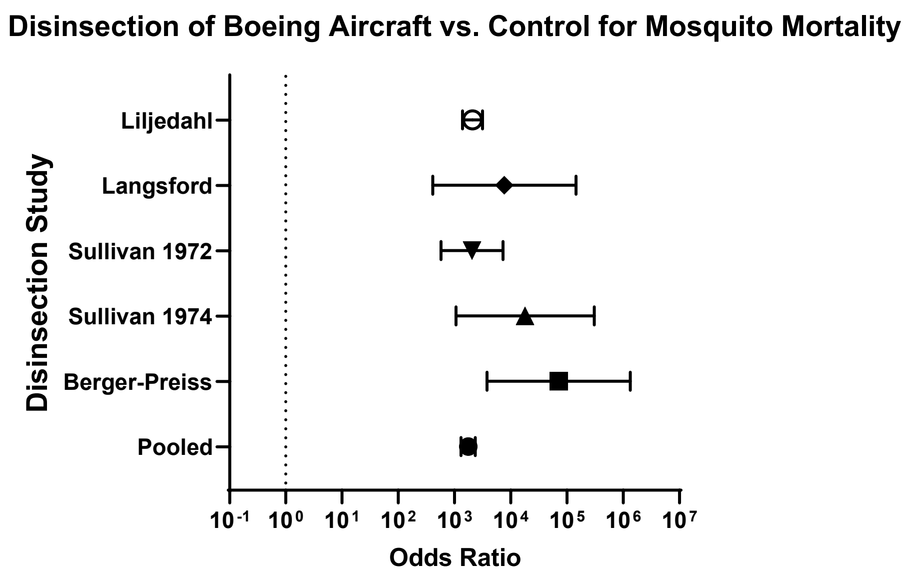


Figure 13. Forest plot of odds ratios of disinsection efficacy for De Havilland aircraft

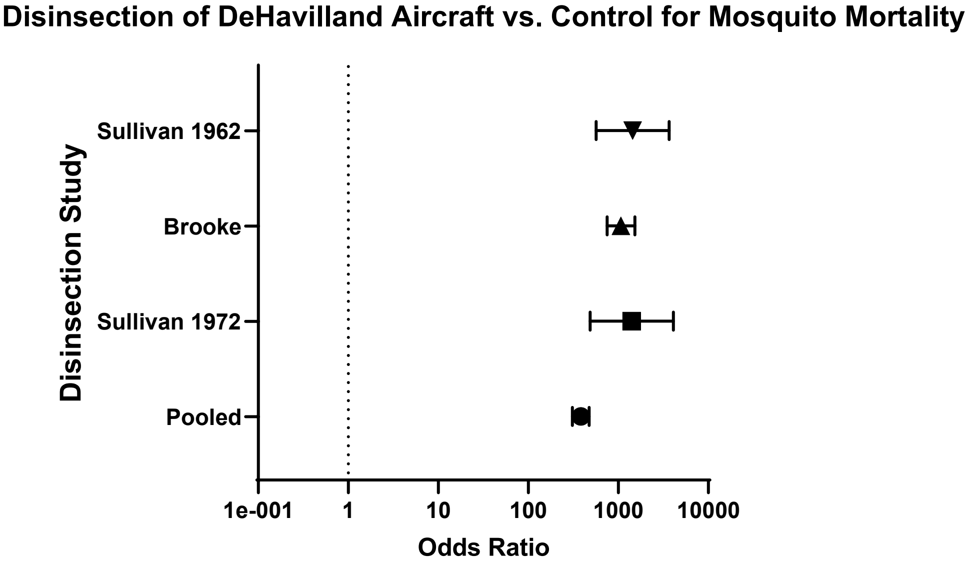
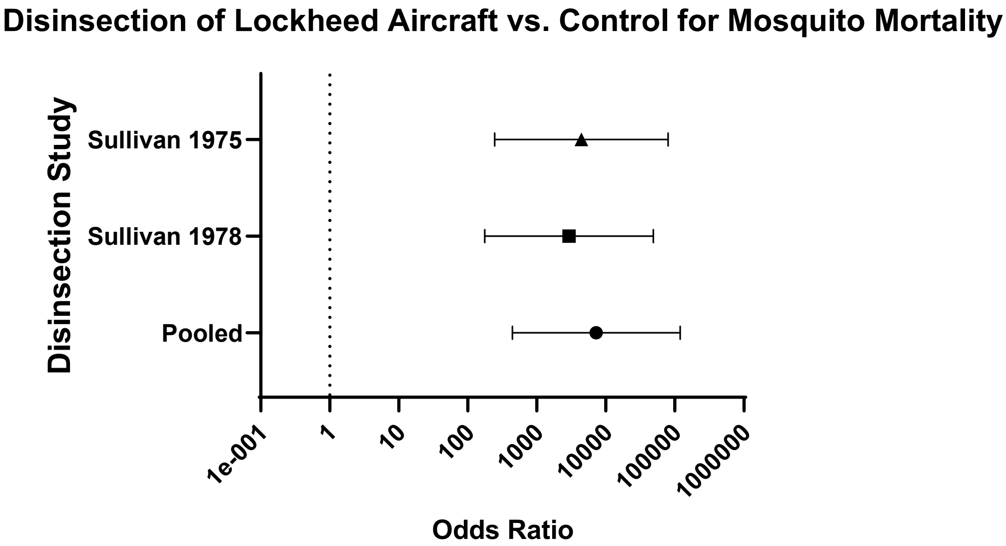


Figure 14. Forest plot of odds ratios of disinsection efficacy for Lockheed aircraft



Finally, the odds of mosquito mortality for disinsection versus control was variable across *different insecticides* (Table 7, Figure 15), ranging from 134.7 (95% CI, 109.6–165.6) for DDT-containing formulations (Figure 16) to 572.6 (95% CI, 424.3–772.6) for resmethrin formulations (Figure 17), with relative risks of 15.46 (95% CI, 12.93–18.52) and 10.61 (95% CI, 8.88–12.73), respectively (Table 7, Figure 15). The only WHO-recommended formulation to be tested in a mosquito-controlled comparator trial was 2% d-phenothrin, which yielded an odds of mosquito mortality for disinsection versus control of 171.7 (95% CI, 139.1–212) across four studies *(32, 33, 40, 46)*, with relative risk of 20.08 (95% CI, 16.53–24.43) (Figure 18). For the insecticide allethrin, the odds of mosquito mortality for disinsection versus control was 264.1 (95% CI, 72.75–958.7), with relative risk of 44.69 (95% CI, 12.74–162.5). For the insecticide bioresmethrin, the odds of mosquito mortality for disinsection versus control was 305.1 (95% CI, 233.9–398.1), with relative risk of 10.06 (95% CI, 8.381–12.11) (Figure 19). For pyrethrin-containing formulations (combined with either Tropital synergist or DDT), the odds of mosquito mortality for disinsection versus control was 163.5 (95% CI, 133.3–200.4) across four studies *(37, 39, 42, 44)*, with relative risk of 16.25 (95% CI, 13.61–19.44) (Figure 20).

Figure 15. Forest plot of odds ratios of disinsection efficacy according to insecticide

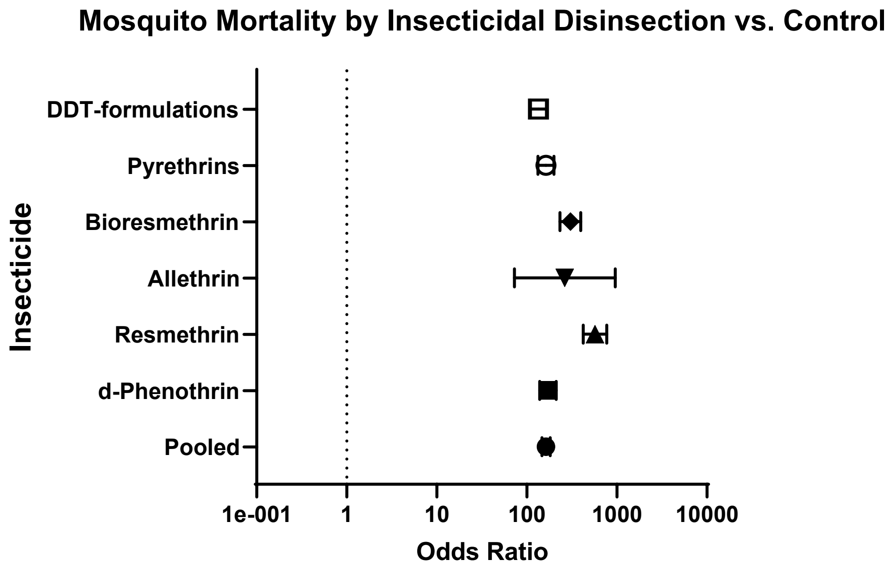


Figure 16. Forest plot of odds ratios of disinsection efficacy for DDT-containing insecticides

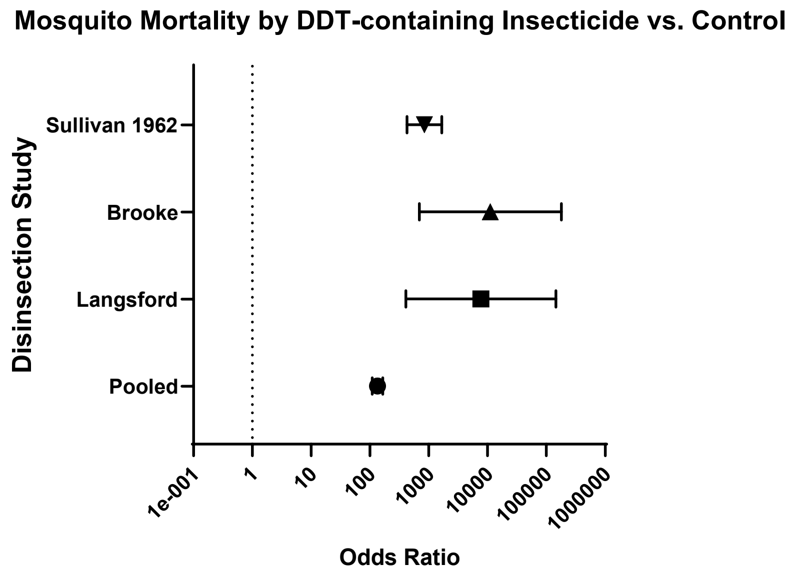


Figure 17. **Forest plot of odds ratios of disinsection efficacy for resmethrin insecticide**

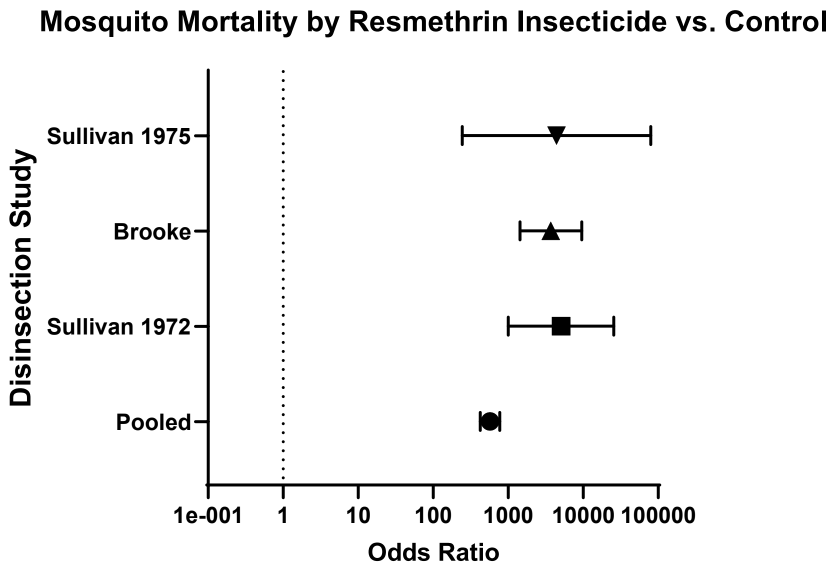


Figure 18. **Forest plot of odds ratios of disinsection efficacy for d-phenothrin insecticide**

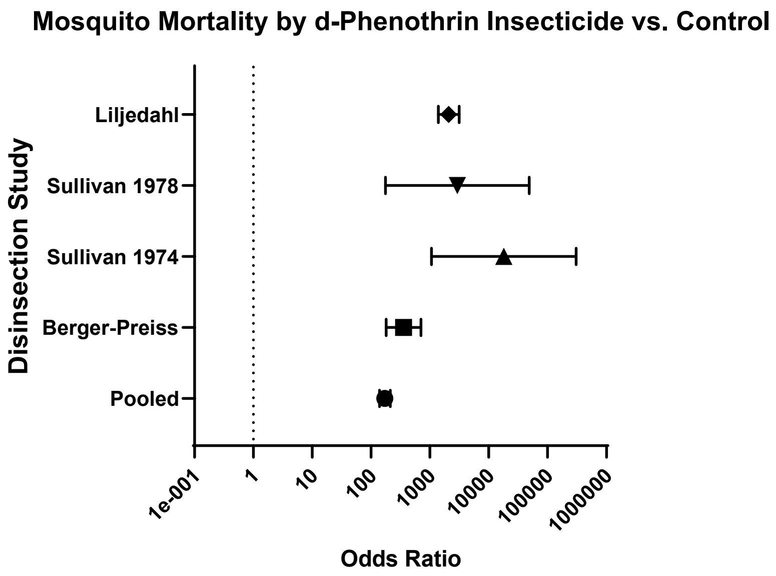


Figure 19. Forest plot of odds ratios of disinsection efficacy for bioresmethrin insecticide

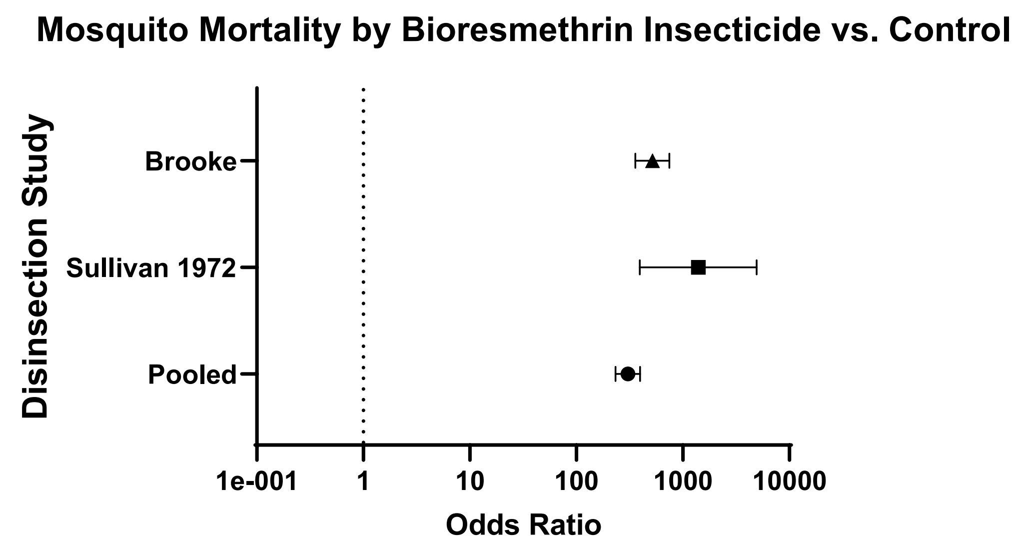
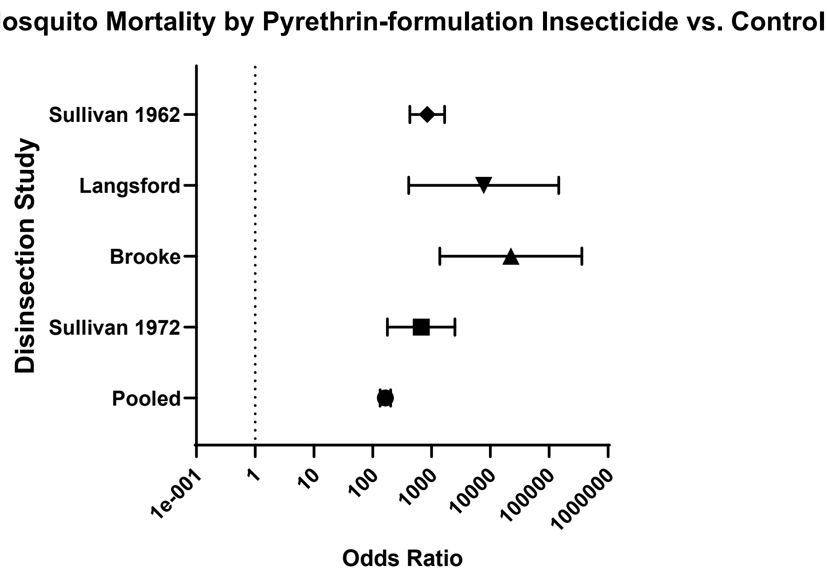


Figure 20. Forest plot of odds ratios of disinsection efficacy for pyrethrin (pyrethrum extract)-containing insecticides



3.9.2 Summary of findings: human safety and toxicity

A quantitative synthesis of aircraft disinsection safety, toxicity and tolerability can be found in Table 8. Where age or sex were reported *(53–55, 57, 60, 61)*, participants were mostly in young to middle adulthood, with men outnumbering women at a ratio of 1.75 to 1. Participants also largely represented those employed by the aviation industry as flight attendants, crew, pilots, technicians or engineers *(37, 38, 40, 42, 43, 49, 54–60, 62)*, authors of the studies themselves *(33, 37, 40, 51, 52)*, and passengers *(42–44, 49, 56, 60–62)*.

Table 8. Summary of findings: safety, toxicity and tolerability of disinsection

Insecticide compared to control (no insecticide) during disinsection of conveyances
Population: humans
Setting: aircraft
Intervention: disinsection
Comparison: no disinsection
Outcome: objective and subjective human health effects

Stratification	No. of studies[a]	Absolute number (%)	Broad human health effects (N, %)	Overall risk of bias	Inc.	Ind.	Imp.	Certainty of evidence (GRADE)	References
Morbidity	3	22/62 (35.5%)	Early retirement (8/42, 19.1) Long-term disability (8/42, 19.1) Hospitalization (14/20, 70) Workdays lost (~78)	Serious	Very high	Very high	Very high	Very low ⊕◯◯◯	Kilburn 2004 Przyborowski 1962 Woodyard 2001
Adverse events	3	16/30 (53.2%)	Blood cell disease (1/1, 100) Anaphylaxis (1/9, 11.1) Seizures (14/20, 70)	NA[b]	NA	NA	NA	NA[b]	Przyborowski 1962 Vanden Driessche 2010 Woodyard 2001
Objective toxicity (per physical examination or laboratory investigation)	9	72/105 (68.6%)	Anaemia, not quantified (16/33, 48.5) Epileptic encephalogram (1/20, 5) Eye conjunctivitis (3/16, 18.8) Impaired cardiovascular function (3/20, 15) Impaired pulmonary function (6/25, 24) Lip oedema (1/4, 25) Skin erythema (2/16, 12.5) Serum/urine insecticide metabolites detected (15/15, 100) (37–87 ppb/0.30–81.5 ppb, respectively)	Very serious	Very high	Very high	Very high	Very low ⊕◯◯◯	Edmundson 1970 Kilburn 2004 Maddock 1961 Przyborowski 1962 Smith 1972 Sutton 2007 Vanden Driessche 2010 Wei 2012 Woodyard 2001

Stratification	No. of studies[a]	Absolute number (%)	Broad human health effects (N, %)	Overall risk of bias	Inc.	Ind.	Imp.	Certainty of evidence (GRADE)	References
Subjective symptoms	8	119/123 (96.8%)	Cardiovascular (5/12, 41.7) Dermatological (24/54, 44.4) Epistaxis (3/9, 33.3) Fever (2/20, 10) Gastrointestinal (15/51, 29.4) Hair loss (12/33, 36.4) Musculoskeletal (1/20, 5) Neurological (54/102, 52.9) Ocular (13/21, 61.9) Respiratory (20/27, 74.1) SCIP (38/38, 100)	Very serious	Very high	Very high	Very high	Very low ⊕◯◯◯	Bonta 2003 Brooke 1971 Kilburn 2004 Maddock 1961 Przyborowski 1962 Sutton 2007 Vanden Driessche 2010 Woodyard 2001
Subjective tolerability	1	84/591 (14.2%)	Malodour (84/591, 14.2)	Very serious	Very high	Very high	Very high	Very low ⊕◯◯◯	Sullivan 1972

NA: not applicable; ppb: part per billion; SCIP: symptoms consistent with insecticide poisoning.

GRADE Working Group grades of evidence: Inc: inconsistency; Ind: indirectness; Imp: imprecision.

a. Insufficient data reported from remaining studies represented in Table 4A and 4B to be considered in calculation.

b. Case series only, risk of bias and GRADE cannot be determined.

Among studies reporting attributable morbidity in just over one third of eligible participants *(54, 58, 60)*, notable findings included eight individuals (19%) reporting early retirement due to symptoms related to disinsection, eight individuals (19%) reporting long-term disability related to disinsection, 14 individuals (70%) reporting hospitalization, and an estimated 78 workdays lost due to disinsection (Table 8).

Among studies reporting specific adverse events attributable to aircraft mosquito disinsection in more than 50% of eligible participants *(58, 60, 61)*, notable findings included one case of anaphylaxis, one case of blood cell disorder, and 14 cases of seizure (Table 8).

Among studies reporting objective evidence of toxicity attributable to aircraft mosquito disinsection in almost two thirds of eligible participants *(33, 51–55, 57–61)*, notable findings included detectable serum or urinary metabolites of insecticides (15/15 tested) *(55, 57)*; epileptic encephalogram (5%); impaired cardiovascular function (15%); and impaired pulmonary function (24%). Additionally, objective signs of insecticide toxicity included conjunctivitis (19%); lip oedema (25%); skin erythema (12.5%); and anaemia (48.5%) (Table 8). One study with a comparator arm of unexposed controls *(54)* noted that exposed flight attendants had a significantly higher number of neurocognitive abnormalities on objective and validated testing compared to unexposed controls (mean 2.8 versus 1.2, respectively), and one cohort study of flight attendants, both exposed and unexposed to disinsection, demonstrated significantly elevated urinary concentrations of pyrethroid metabolites in those flying disinsected routes compared to those not *(55)*. Moreover, the urinary concentration of pyrethroid metabolites in the unexposed flight attendants (that is, those not flying routes that were disinsected) did not differ from that of the general population *(55)*. The flights conferring the highest urinary metabolites of pyrethroids in exposed flight attendants were those to and from Australia *(55)*.

Among studies reporting subjective symptoms attributable to aircraft mosquito disinsection in 97% of eligible participants *(37, 40, 52, 54, 56, 58–62)*, notable findings included reports of systemic symptoms including fever (10%) and myalgia (5%); dermatologic symptoms such as rash (44%) and hair loss (36%); neurologic symptoms (53%) such as numbness, impaired concentration, loss of consciousness, headache and impaired memory; respiratory symptoms (74%) such as shortness of breath; cardiovascular symptoms (42%); gastrointestinal symptoms (29%) such as nausea and diarrhoea; and finally, other localizing symptoms such as epistaxis (33%) and ocular symptoms (62%) (Table 8). Among 38 eligible participants in one study, 100% had symptoms consistent with insecticide poisoning *(56)*. In the one study with a comparator arm of unexposed controls, the mean frequency of 35 specific symptoms was almost twice that of unexposed controls *(54)*.

Among studies reporting subjective tolerability in the absence of specific symptoms *(38, 40, 42, 44, 49, 60, 62, 63)*, malodour was reported by 14% of participants (Table 8).

3.9.3 Summary of findings: outcomes other than efficacy and safety, toxicity and tolerability

In general, WHO's 2018 report on *Methods and operating procedures for aircraft disinsection (8)* cites improper staff training, complexity of procedures and recommendations, and interference with timing of flight departures as the issues with the greatest impacts on operational efficiencies. User acceptability is challenged by the wet and sticky surfaces of residual disinsection methods, and the visible exposure of passengers to insecticides with the "blocks away" and "top of descent" methods. Further, the report cites the absence of an approved product in Europe for pre-embarkation aerosol spraying, which requires 2% permethrin formulations, as well as the need to pair "top of descent" spraying with a pre-flight method, as challenges to disinsection feasibility. Residual disinsection has been reported to compromise the integrity of aircraft surfaces, and a concern regarding excess exposure of passengers to insecticide was noted in the event of residual treatment of aircraft seating. Finally, concerns for the health and safety of crew and passengers were noted with all methods of disinsection, particularly in the context of non-compliance with recommended application protocols *(8)*.

Of the primary literature reporting secondary or other outcomes of interest, very few reported common outcomes in a consistent manner or collected data in ways permissive to true quantitative or qualitative synthesis.

Among the 19 studies or reports describing *user acceptability (32, 33, 38–45, 47–49, 56, 60, 62–65)* (Tables 3–6), one study inferred user acceptability due to the low dermal and inhalational exposure to insecticide with pre-embarkation methods *(33)*; one study reported better acceptability of odour by crew with the lowest concentrations of insecticide used, with some noting a pleasant odour *(38)*; one study noted that passengers were simply unaware of the disinsection procedures *(49)*; one study noted that adherence to protocols regarding closure of passenger air vents and cessation of air conditioning resulted in an acceptable in-cabin air temperature *(39)*; two studies reported that odour or irritation from disinsection were undetectable by crew, pilots or scientists over a series of applications *(32, 40)*; one further study reported that dichlorvos spared passengers irritation of eyes and airways *(63)*; one study noted that aircraft disinsection demonstrations were “favourably commented on by the majority of observers” *(48)*; one study noted that exclusion of bioresmethrin and resmethrin as test agents occurred due to offensive odour and that the two pyrethrin-based sprays had high irritant respiratory effects on personnel *(41)*; one study reported “general” acceptance of “top of descent” spraying by passengers, although some passengers expressed concerns about allergic reactions *(47)*; two studies reported no user acceptability issues with SRA *(42, 43)*, although the use of G-1480 (with higher pyrethrum concentrations) led to unfavourable reactions on all flights with use, including a marked irritant effect *(42)*; one study reported that at least two thirds of passengers surveyed “liked or did not care about” the insecticide being used across multiple different concentrations of three different insecticides, though a statistically significant passenger objection rate to 2% versus 1% insecticide formulations was reported *(44)*; one study noted a similar proportion of passengers detecting an “unpleasant odour” before and after “top of descent” spraying *(45)*; one review noted that passengers complained of “heavy air” and unpleasant odours, particularly during longer disinsection procedures, including pre-embarkation methods *(62)*; one study noted that personal protective equipment (PPE) was not recommended for flight attendants, as its use reduced passenger acceptability *(56)*; one study mentioned that passenger reactions to insecticides were a problem in the implementation of disinsection protocols *(64)*; one study reported initial resistance to disinsection from military personnel but eventual acquiescence *(65)*; and one grey literature report noted that passengers, flight attendants and pilots complained about odour and actively attempted to escape disinsection procedures *(60)*.

Of five studies reporting *effects on equipment (34, 36, 41, 46, 56)* (Tables 3–6), one study noted that micronized dusts accumulated on vertical surfaces *(34)*; one study noted that application of lindane produced “objectionable spotted surfaces” in passenger areas *(36)*; one study noted that problems with electronic equipment on Qantas B747 aircraft “appeared to be attributable” to applications of d-phenothrin *(41)*; one study noted an absence of deleterious effect of disinsection on aircraft internal structures *(46)*; and one study noted the presence of visible 2.2% permethrin residue on the cabin floor of one flight *(56)*.

Of the 16 studies reporting *operational efficiencies (35, 41–43, 47, 48, 50, 58, 63, 65–71)* (Tables 3–6), one study noted minor defects in the structure of the disinsection apparatus or method of using it *(48)*; one study noted that the recovery of permethrin from surfaces was considerably less than the applied (and intended) amount, which may have operational impacts *(35)*; one study noted continued delays with on-arrival spraying and therefore favoured single-spray “blocks away” procedures *(41)*, and similarly one study noted that the "blocks away" procedure eliminated a typical 10-minute departure delay *(42)*; one study noted that "top of descent" spraying eliminated delays associated with on-arrival disinsection *(47)*; one study noted that disinsection interfered with safety briefings *(43)*; one study noted that disinsection procedures were not carried out at all due to efficiency impacts *(70)*; one study noted that American dispensers manufactured by the Milwaukee Sprayer Manufacturing Co. had very rapid output that challenged even distribution, leading to a "compact cloud" of insecticide *(50)*; one study noted that the change from a solution to aerosol bombs facilitated the disinsection process, thereby improving efficiency *(65)*; one study noted the logistical challenges of disinsecting aircraft wheel bays due to potential accumulation of grease and oil on surfaces, thereby limiting the effectiveness of residual insecticides *(71)*; one study noted the tedium of disinsection before disembarkation, leading to "discomfort" of passengers and crew *(66)*; one study noted the difficulty in thoroughly examining planes peri-disinsection due to time constraints and the presence of passengers, luggage and cargo *(67)*; and one study recommended turning aircraft air conditioning off prior to cabin treatment *(69)*, in accordance with existing WHO procedural recommendations but contrary to common practice. One study of marine and air conveyances noted that disinsection of ships may impede flow of traffic and that the "blocks away" method of aircraft disinsection caused the least travel delay *(63)*. Finally, one study of marine conveyances noted that permethrin spraying and monitoring increased the workload of Ministry of Agriculture and Forestry inspectors *(68)*, and a further study aboard a ship noted that additional cleaning and washing of warehouses was required and that food products aboard were destroyed by leaking insecticide *(58)*.

Of the three studies reporting *financial impact* to passengers and fiscal considerations in general *(66, 72, 73)* (Table 6), one study noted that all costs were charged to the airlines *(72)*; one study noted that in addition to financial impacts on the aviation industry, extra costs associated with aircraft disinsection were also borne by health authorities *(66)*; and one study noted the cost–effectiveness of eliminating mosquitoes at international borders rather than once mosquito populations were established *(73)*.

Of two studies specifically reporting on disinsection *feasibility (39, 43)* (Table 3), one study reported that crew found handling of dispensers to be awkward on the DC-8 aircraft, with easier use of larger-volume dispensers *(43)*, while another reported that adhering to guidelines on switching off the aircraft air conditioning was deemed feasible, given that passengers were able to tolerate the cabin temperature *(39)*. However, the study noted that the taxi time of less than four minutes, a low passenger load, and lower ambient temperature outside all contributed to a lack of rising temperature in the aircraft upon disinsection *(39)*, which would not necessarily generalize to typical circumstances of disinsection.

Of four studies reporting on *carriage of pathogens* by mosquitoes identified aboard or in proximity to conveyances *(66, 74–76)* (Tables 5 and 6), one study reported assaying a single adult *Ae. aegypti* mosquito detected at Narita International Airport for flavivirus and chikungunya genes, both of which were negative *(74)*; one study reported examining female *Culex* spp. mosquitoes found aboard aircraft in Singapore for microfilariae, none of which was positive *(66)*; and one study tested 21 *Aedes* spp. mosquitoes found aboard cargo ships at ports of Los Angeles for flaviviruses including dengue, Japanese encephalitis, Murray Valley encephalitis and Saint Louis encephalitis, all of which were negative *(75)*. One report identified West Nile-infected adult mosquitoes at an American naval submarine base *(76)*, and as such implemented insecticide spraying in and around the base.

Of seven studies reporting on the outcome of *public health and health systems impact (56, 65, 72, 73, 77–79)* (Tables 4 and 5), one study noted the need for broader environmental health services available to air travellers in advance of travel in general *(72)*, and one study reported that aircraft disinsection procedures in Hawaii were conducted by expert entomologists, the salaries for whom were paid by the Hawaiian Sugar Planters' Association, and board, accommodation and transportation for the entomologists by Pan American Airways *(77)*. One study noted the potential safety issue of transfusion-transmitted malaria that might occur due to undetected airport-acquired infection *(79)*, and one study commented on how crucial disinsection was in preventing the reintroduction of *Anopheles gambiae* and other pests into Brazil *(65)*. One surveillance report *(56)* recommended the following public health oriented actions: (a) health agencies should evaluate the effectiveness of disinsection and investigate non-toxic methods; and (b) airlines should educate and monitor the health of workers and passengers as it related to disinsection hazards, restrict crew access to aircraft for four hours post-disinsection and refrain from spraying in crew rest areas, ensure maximum ventilation, implement quality control for pesticide application, and schedule flights to minimize the number of treated aircraft. Further, one study of marine conveyances reported that the sea container pathway of mosquito importation was the least well controlled of all ports in New Zealand *(73)*. Finally, one study of marine conveyances reported that the Quarantine (Sailing) Boats Regulations of Sudan were established in 1944 in response to *Aedes* spp. infestations on dhows, and ensured that boats could not depart without a public health clearance certificate stating the ship had been inspected and found to be mosquito free within 48 hours of departure *(78)*.

Of two studies reporting on *legal considerations* of disinsection *(60, 80)* (Tables 4 and 5), one study reported that the interception of *Ae. albopictus* mosquitoes in shipments of used tyres led to the drafting and implementation of Public Law 78-410, Public Health Service Act, Section 361, and 42 CFR 71.32(c)(10), wherein the United States Centers for Disease Control and Prevention required used tyre casings from Asia to be legally certified as dry, clean and free of insects *(80)*. Another report noted that three lawsuits related to disinsection were filed by passengers and employees against United Airlines, and an attorney against five insecticide manufacturers *(60)*. For the lawsuit for which information is available publicly, the court, under the Warsaw Convention, ruled that injuries from standard operations of aircraft were non-accidental, and as disinsection was routine for United Airlines and legally required by Australia, it was deemed a necessary part of standard operations, even if passengers were not informed a priori. As such, that case was dismissed *(60)*. No studies reported on the potential legal considerations in situations where country-level regulations on use of insecticide within occupational spaces were in conflict.

Of two studies reporting on *political or sociocultural* considerations of disinsection *(65, 81)* (Table 5), one study noted that the disinsection intervention involved cooperation between Brazilian and American authorities *(65)*, and another study mentioned use of a One Health approach and discussed regional collaboration among countries of the Indian Ocean region to enhance vector surveillance and responsiveness *(81)*.

The two studies reporting on *insecticide resistance (35, 80)* noted that susceptibility testing of *Ae. albopictus* adults found aboard cargo ships in Seattle, Washington, and Oakland, California, demonstrated increased resistance to bendiocarb, malathion and temephos *(80)* (Table 5). The other study *(35)* reported that among 79 mosquitoes captured at eight Australian airports, knockdown resistance mutations were present in 67% (n=53) (Table 6). In that study, the investigators also exposed *Ae. aegypti* adults to known knockdown resistance mutations to permethrin-treated carpets in a model of residual disinsection, and found that mortality was < 50% after 30 minutes of exposure *(35)*. However, it is unclear whether or not the experimental data were accrued on an actual aircraft versus a modelled laboratory setting.

3.9.4 Summary of findings: identification of mosquitoes aboard conveyances

Across 34 studies reporting on mosquito surveillance aboard *aircraft (3, 41, 64–67, 70–72, 74, 77, 79, 82, 83–103)*, 26 reported *quantitative* adult mosquito datasets comprising 39 548 adult mosquitoes *(41, 65, 66, 67, 70, 74, 77, 82–91, 93–95, 97–99, 102, 103, 112)*, with representation across vector-capable *Aedes*, *Anopheles* and *Culex* species (Table 5). Among the 26 studies reporting quantitative adult mosquito data as well as one study not reporting quantitative data, 11 reported the detection of mosquito species *novel* to the country in which the aircraft surveillance was undertaken *(74, 85, 88, 91, 94, 95, 97–100, 112)*, with multiple novel detections of *Ae. aegypti (74, 85, 100)*, *Anopheles gambiae (99, 112)* and *Culex quinquefasciatus (94, 97, 98)*, as well as multiple other vector-capable species of *Aedes*, *Anopheles* and *Culex* (Table 5). No novel detections of *Ae. albopictus* were reported aboard aircraft; however, this species was documented as an endemic species on aircraft surveyed in Singapore *(66)* and, similarly, endemic *Ae. aegypti* adults were documented on aircraft surveyed in Singapore *(66)*, New Zealand *(102)*, Australia *(41)* and the southern United States of America *(91)*.

In 1975, astronauts departing earth from Kennedy Space Center in Florida noted the presence aboard of a large adult mosquito, and in 1984, aboard spacecraft *Discovery*, another adult mosquito was noted to be flying around in weightlessness *(111)*. The mechanism by which mosquitoes accessed the spacecraft interior was unclear in each case.

Across nine studies reporting on mosquito surveillance aboard *marine conveyances (68, 69, 75, 80, 104–108)* (Table 5), three reported quantitative adult mosquito datasets comprising 365 adult mosquitoes *(68, 107, 108)*, with representation across vector-capable species such as *Ae. albopictus* and *Ae. japonicus (68)*, *Ae. aegypti (107)* and *Culex* spp. *(107)*. Four surveillance studies of mosquitoes aboard marine conveyances did not report the number of adults detected, but again reported many species capable of vectoring human pathogens, including *Ae. albopictus* identified aboard cargo ships in the ports of Los Angeles *(75)*, *Ae. aegypti* identified in approximately 6% of ships surveyed in Georgetown, Guyana *(106)*, and *Anopheles maculipennis* identified on a ship in New Zealand *(104)*. One study that surveyed ships in ports of California did not detect any adult mosquitoes (though noted larvae of *Ae. aegypti*) *(105)*, and another study reported on shipments of tyres to Seattle and Oakland where no adult mosquitoes were detected (though larvae of *Ae. albopictus* were noted) *(80)*. Novel detection of both *Ae. albopictus* and *Ae. japonicus* aboard cargo ships in New Zealand was reported by one study *(68)*.

Across six studies reporting on mosquito surveillance aboard *aircraft and marine conveyances (63, 73, 81, 101, 109, 110)* (Table 5), four reported quantitative adult mosquito datasets comprising 8870 adult mosquitoes *(73, 81, 101, 109)*, with representation across vector-capable species such as *Ae. albopictus (81)* and *Anopheles gambiae (101)*, as well as a spectrum of other *Aedes*, *Anopheles* and *Culex* species *(73, 109)*. One further study of aircraft, dhows and ships in Sudan *(110)* noted the presence of *Aedes aegypti* adults aboard surveyed conveyances, though did not report the number detected. Another surveillance report regarding a ship docking in Sri Lanka did not specify the number of adult mosquitoes identified *(63)*.

The one study that reported mosquitoes aboard dhows, trains and aircraft in Sudan *(78)* detected species including *Ae. aegypti*, *Anopheles gambiae*, and several other vector-capable species of *Anopheles* and *Culex* (Table 5).

Finally, in August 1996, three cases of true “airplane malaria” were reported in Brazil, after passengers travelling in the first-class cabin on a flight from Lebanon to São Paolo with a 30-minute stop in Abidjan, Côte d’Ivoire, became ill with falciparum malaria *(112)*. Aboard the aircraft in São Paolo, four adult *Anopheles gambiae* mosquitoes were detected, three of which were detected in the first-class cabin and another one in the luggage compartment. This report is unique in that the epidemiological investigation undertaken identified vector-capable adult mosquitoes on the very aircraft implicated in transmission. As such, the causality was unequivocal (Table 5).

3.9.5 Summary of findings: identification of mosquitoes at international points of entry

Across 10 studies reporting *quantitatively* on mosquito surveillance at international airports *(35, 74, 113–117, 119–121)*, 12 380 adult mosquitoes were identified, with representation across vector-capable *Aedes*, *Anopheles* and *Culex* species (Table 6). In the study reporting surveillance for *Anopheles* mosquitoes at airports in Dakar, Yaoundé, Abidjan and Cotonou, a total of 111 adults were identified representing *Anopheles gambiae*, *An. arabiensis* and *An. pharoensis (116)*. Such adults were isolated from the tarmac (n=43), the luggage loading area (n=68) and inside the luggage container (n=2) *(116)*. In one study conducted at Paya Lebar International Airport in Singapore *(118)*, the total number of adult mosquitoes identified was not reported; however, the species identified represented *Ae. albopictus*, *Ae. aegypti* and *Culex pipiens fatigans* (now *Cx. quinquefasciatus*). In another report of mosquitoes collected in airfields of sub-Saharan Africa (West Africa) and Brazil *(99)*, the total number of adult mosquitoes identified was not reported; however, the species identified represented *Anopheles gambiae*.

Novel detection of species non-endemic to the point of entry in which they were detected occurred in Australia, where *Ae. aegypti* was found at eight airports surveilled *(35)*, and in Hawaii, where *Anopheles punctipennis* was found at Honolulu International Airport *(115)* and where *Ae. japonicus* was found at Hilo and Waimea Airports *(119)* (Table 6). The study by Ong and colleagues reported that an “unprecedented” number of exotic mosquitoes had been detected through routine surveillance of Australian airports *(35)*.

In a Russian Federation experiment conducted at the International Space Station, an adult mosquito was able to survive in the weightlessness of space outside the Space Station for 18 months *(132)* (Table 6).

Across three studies reporting *quantitatively* on mosquito surveillance at international *seaports (122–124)*, 33 093 adult mosquitoes were identified, with a predominance of vector-capable *Aedes*, *Anopheles* and *Culex* species reported (Table 6). In one report, adult mosquitoes were identified at an American naval submarine base, and were found to be harbouring West Nile virus *(76)*.

An additional study of mosquito surveillance at both *airports* and *seaports* in Cyprus *(128)* reported 458 adult mosquitoes comprising almost entirely *Aedes* (including *Ae. albopictus* and *Ae. aegypti*) and *Culex* species, without identification of *Anopheles* spp. (Table 6). In five studies of mosquito surveillance at airports and seaports of Belgium *(125)*, the United Kingdom of Great Britain and Northern Ireland *(126, 129)*, throughout the Caribbean *(63)* and Australia *(127)*, the number of adult mosquitoes identified was not reported. In three such studies, *Ae. albopictus* was reported in Belgium *(125)*, Australia *(127)* and Cyprus *(128)*, while in one such study, *Ae. aegypti* was reported throughout the Caribbean *(63)* (Table 6).

In one study synthesizing the literature on the identification of *Ae. albopictus* at air, sea and land ports across Europe *(130)*, the number of adult mosquitoes identified was not reported.

Finally, one further study conducted at a rail station in Freiburg, Germany, that serviced a line from Italy *(131)* detected over 4000 adult *Ae. albopictus* mosquitoes during the four-month surveillance period, representing a significant expansion since its first detection in Germany in 2007 (Table 6).

No studies of seaports, rail stations or highways identified novel detection of particular mosquito species. However, three surveillance reports at international airports noted novel detection of one adult of *Anopheles punctipennis* in Honolulu *(115)*, 29 adults of *Ae. japonicus* in Hilo and Waimea *(119)* and 79 adults of *Ae. aegypti* in surveyed international Australian airports *(35)*.

Four reports that summarized cases of airport malaria in Europe included six cases of *P. falciparum* attributed to transmission in or around Roissy Charles de Gaulle Airport in Paris *(133)*, six cases of *P. falciparum* attributed to transmission at the International Airport in Brussels *(135)*, and 66 cases across European international airports representing a range of *Plasmodium* species, but predominantly *P. falciparum (116, 134)* (Table 6). In the six cases reported by Giacomini and colleagues in 1995 *(133)*, three cases were among airport employees who regularly worked night shifts in the baggage area, security and on track maintenance, and as such were convincingly exposed to nocturnal biting imported *Anopheles*. Another case unpacked mail routinely from Africa, and as such transmission occurred via mail-based importation *(133)*. In two of the six cases reported, the causal relationship between Charles de Gaulle Airport and falciparum malaria was unclear *(133)*. In the six cases reported by Van den Ende and colleagues in 1995, three cases occurred among Brussels Airport security employees and three cases among visitors to the arrival hall during a period of prolonged high temperatures in Belgium *(135)*. The many cases summarized in the papers by Giacomini and by Guillet and colleagues represented a range of causal certainty, with some cases clearly linked to airport exposure and some not *(116, 134)*.

3.9.6 Health equity and human rights considerations

The body of main and supporting literature related to human safety and toxicity of disinsection reported very few of the PROGRESS-CANDALS factors and did not stratify the occurrence of specific outcomes according to such factors. In general, only a handful of studies or reports investigating the human health effects of disinsection, including safety, toxicity and tolerability, reported the sex *(53, 57, 60, 61)* or age *(53–55, 57, 61)* breakdowns of their participants. More studies or reports of human health effects noted participants' occupations as flight attendants, pilots and crew *(38, 40, 42, 43, 49, 54–56, 58–60, 62)* or technicians and engineers *(37, 57)*, as such employment engendered occupational exposure to disinsection. However, no studies stratified their findings according to PROGRESS-CANDALS factors, as none were sufficiently designed or powered for such subgroup analyses.

Credit: WHO / Halldorsson
Verano Monumental Cemetery in Rome, Italy, is an ideal breeding ground for Aedes albopictus – the Tiger mosquito – due to the hundreds of thousands of flower pots with stagnant water, scattered across the cemetery. The Tiger mosquito can transmit dengue virus to humans.

4. Conclusion

In conclusion, the systematic review identified only four mosquito-controlled comparator trials investigating the efficacy of a WHO-recommended insecticide formulation (2% dphenothrin) for the purpose of aircraft disinsection, which supported a high degree of insecticidal efficacy. Studies on 2% permethrin or 2% 1R-trans-phenothrin were not identified, although the latter product is a more toxic isomer of d-phenothrin. Furthermore, no studies (of 19 included) of any insecticide identified by the systematic review adhered to WHO recommendations for conduct of such experimental trials, and the true efficacy of such disinsection procedures in a real-life context is thus uncertain. The evidence base upon which current disinsection guidance is predicated predates the publication of WHO's process-oriented guidelines for investigating disinsection efficacy and, as such, the evidence base warrants updating to current methodological and reporting standards. While some secondary outcomes in disinsection trials were reported, including operational efficiencies, user acceptability, impacts on public health and health systems, legal considerations, financial impact, and impacts of insecticides on the integrity of conveyances, this literature base is of equally low quality with significant risk of bias. Many knowledge gaps remain, particularly with regard to feasibility of performing disinsection procedures in accordance with current guidance (for example, with air conditioner switched off while passengers are on board), environmental impacts and generation of insecticide resistance amongst mosquitoes. Moreover, reports of health equity and human rights considerations of disinsection were absent from the included literature.

Of particular concern is the breadth and quality of evidence surrounding human health impacts, as no high-quality studies investigating the safety, toxicity or tolerability of disinsection were identified. Rather, the literature base describing human health effects of disinsection comprises very limited post hoc public health surveillance, small cohort studies, one unmatched case–control study, case series and case reports. Experimental trials that did comment on safety and tolerability in humans were primarily designed to test insecticidal efficacy of disinsection, and standard human subject considerations and measures of methodological rigour in clinical research were largely ignored or not reported. The one highest-quality cohort study (which reasonably adhered to acceptable standards of methodological rigour) of flight attendants noted demonstrable elevations of urinary pyrethroid metabolites in those flying disinsected routes compared to those who did not. However, the human health impacts of such elevated urinary metabolites remain unknown. This scant literature base has a high risk of bias; however, given the reports of significant morbidity, adverse events, and toxicity putatively and objectively attributable to aircraft disinsection, well designed clinical trials investigating the full range of human health impacts of disinsection on passengers and crew are urgently needed. Even if the attack rate is ultimately low due to the huge denominator of exposed travellers and crew, the severity of adverse health effects reported by the limited studies included herein substantiates the need for much greater exposition regarding safety and toxicity risks.

Surveillance of air, marine and land conveyances and their proximities at points of entry identified vector-competent adult mosquitoes of clinically important species across *Aedes*, *Anopheles*, *Culex* and other genera. Notable detection of particularly relevant species, such as *Ae. aegypti* aboard aircraft in Japan and the United Kingdom of Great Britain and Northern Ireland and *Ae. albopictus* at points of entry in Belgium and Germany, where these species are non-endemic, underscore the potential for vector conveyance globally. Included cases of airport and airplane malaria were convincingly linked to mosquito exposures in aircraft cabins, cargo holds, baggage handling areas and via airmail, while two reports of mosquitoes aboard spacecraft highlight the insect's ability to access human-created environments from which its exclusion – for reasons of health, safety and potential dissemination – should be absolutely assured. The rationale for surveillance of aircraft, marine vessels and their respective points of entry, including rail stations, for adult mosquitoes was amply supported by the synthesized literature.

5. Research considerations

Developing, testing and establishing standards and performance criteria for non-chemical aircraft cabin disinsection methods (for example, ultraviolet-based, electrostatic, sonic, air curtain) that minimize impacts of disinsection, particularly on human health, as well as internal appliance of conveyances, would be a worthwhile research agenda. Similarly, testing the feasibility, efficacy and safety of already available electrostatic sprayers for residual disinsection, which reduce the amount of spray liquid to be applied in aircraft and other conveyances, could be considered. Future disinsection research endeavours should also consider advancements in aircraft size and design (for example, multi-deck aircraft), requiring that exposure assessments address characteristics such as different aircraft airflow systems and uncertainties in onboard ventilation performance against standards.

Determining the extent to which mosquitoes are present in passenger bridges and walkways, vehicles that transport passengers to the aircraft door, and vehicles transporting luggage to the cargo hold would be a high-priority research agenda. Moreover, the role that passenger luggage plays in conveyance of vectors internationally warrants investigation, as in several cases of airport malaria reported in the medical literature, luggage as a potential source of vector dispersal cannot be excluded. Shipping containers as another mode of international dispersal of vector-competent mosquitoes is a growing concern, but again, one that is underpinned by few or no data, and as such remains a target for future research. Similarly, identifying the optimal methods and procedures for effective and safe marine vessel disinsection – taking into account variable vessel length, cabin composition and duration of voyage – is a worthwhile endeavour, given the absolute dearth of such data.

Surveillance activities for mosquitoes aboard all types of international conveyances and their respective points of entry should be scaled to include systematic investigation of pathogen carriage, as the literature base on this topic is particularly scant. Further to this research agenda is disentangling the role of internationally conveyed mosquitoes in the development of locally established foci of vector-borne diseases, and how currently recommended disinsection procedures may mitigate or prevent such novel introductions.

Finally, the notion that mosquitoes can board spacecraft warrants particular attention, given the enhancements to national aerospace programmes throughout the world. Development of a mosquito-borne infection such as malaria or dengue could be catastrophic in space, and dedicated surveillance activities to better understand how mosquitoes and insects have been able to access spacecraft could be considered.

6. Uncertainties and knowledge gaps

The high efficacy of disinsection procedures evaluated in the studies reported herein must be interpreted in the context of a high degree of non-adherence to published guidelines on necessary methodological aspects of such trials. No included studies adhered fully to recommended study procedures *(31)*, and consequently the generalizability of findings is uncertain. Similarly, high-quality studies evaluating the safety, toxicity and tolerability of aircraft disinsection were unidentifiable through our search strategy, and if such data exist, they are absent from the published medical literature and grey literature that is publicly available. The long history of insecticide approval for use aboard aircraft and in many other occupational and household contexts is almost certainly underpinned by human safety and toxicity data that were unavailable publicly and unidentifiable by our search strategy. Making such reports available, not just to regulatory agencies responsible for adjudicating safety but to all stakeholders, including the public, in a comprehensive and organized manner is a matter of urgency. Moreover, while occupational health surveillance is necessary, the exposure of any person to products with potential toxicity, allergy, intolerance or bioaccumulation in tissues should be avoided if the results of such tests are not publicly available through manufacturers. Coordination and cooperation within both regulatory and scientific efforts is imperative.

Based on the types and quality of safety and toxicity reports included, the human health effects of aircraft disinsection procedures are unknown. What literature does exist is concerning for a potential safety signal, and it is therefore a matter of urgency to establish safety and toxicity specifically of aircraft disinsection through methodologically rigorous, prospective, registered, institutional review board-approved, sufficiently powered, placebo-controlled human trials with adequate post-exposure follow-up. Reported outcomes in such trials should focus on the safety and toxicity of insecticides across the human lifespan and across the range of exposures one would expect to encounter, both occupationally and as a passenger. Moreover, a specific focus of safety and toxicity outcomes in the most vulnerable of potentially exposed individuals – including children, pregnant women and women of childbearing age, and those marginalized according to PROGRESS-Plus[11] factors – should be prioritized, and studies should be sufficiently powered to report their outcomes accordingly.

The current guidelines on methodological aspects to include in studies of disinsection efficacy are process oriented, and we could locate no corollary guidance document for evaluating aircraft and conveyance disinsection safety and toxicity.

Relative to international conveyance volumes, there is a dearth of surveillance data obtained from operational conveyances at points of entry, and more comprehensive surveillance is required to disentangle the causal relationship between transport of vectors via conveyances and global emerging infectious diseases such as dengue. Significant international coordination and cooperation will be required for such an ambitious but worthwhile endeavour. Similarly, the inclusion of systematic and large-scale pathogen detection initiatives within conveyance-related surveillance programmes represents an opportunity to close a substantial knowledge gap, one that necessitates concerted attention in today's climate of mass international transit, vector range expansion and globalization of infectious diseases. Notably, the role of disinsection measures imposed at points of entry in preventing or mitigating the importation of vector-borne diseases such as dengue into non-endemic regions remains uncertain. Moreover, how conveyance disinsection as a strategy fits into a multilayered approach to prevention of mosquito dispersal internationally is uncertain; however, it is near-certain that national strategies cannot rely on disinsection alone.

Furthermore, the causal relationship between vector-competent mosquitoes identified in and around points of entry to specific international conveyances and the establishment of novel distant breeding foci, along with both pathogen transmission and emergence of insecticide resistance, is unclear. Prospective research agendas designed to close such knowledge gaps are of paramount importance.

[11] PROGRESS-Plus: place of residence, race/ethnicity, occupation, gender/sex, religion, education, socioeconomic status and social capital, plus other characteristics such as age, disability or relationships.

References

1. WHO aircraft disinsection methods and procedures, second edition. Geneva: World Health Organization; 2023 (https://iris.who.int/handle/10665/374318, accessed 10 September 2024).

2. Report of the informal consultation on aircraft disinsection, Geneva, 6–10 November 1995. Geneva: World Health Organization, International Programme on Chemical Safety; 1995 (https://iris.who.int/handle/10665/59700, accessed 10 September 2024).

3. Gratz NG, Steffen R, Cocksedge W. Why aircraft disinsection? Bull World Health Org. 2000;78(8):995–1004. PMID:10994283.

4. International Health Regulations (2005), third edition. Geneva: World Health Organization; 2016 (https://apps.who.int/iris/handle/10665/246107, accessed 10 September 2024).

5. Airport vector control register. In: Crises and rapid response programme [website]. Montreal: International Civil Aviation Organization, Uniting Aviation; 2020 (https://www.icao.int/crr/Pages/Airport-Vector-Control-Register.aspx, accessed 10 September 2024).

6. Guide to ship sanitation, third edition. Geneva: World Health Organization; 2011 (https://www.who.int/publications/i/item/9789241546690, accessed 10 September 2024).

7. WHO ad hoc advisory group on aircraft disinsection for controlling the international spread of vector-borne diseases, Geneva, Switzerland, 21–22 April 2016: meeting report. Geneva: World Health Organization; 2016 (https://iris.who.int/handle/10665/205795, accessed 10 September 2024.

8. Methods and operating procedures for aircraft disinsection: report of a WHO consultation, Geneva, 3–4 July 2018. Geneva: World Health Organization; 2018 (https://iris.who.int/handle/10665/279702, accessed 10 September 2024).

9. WHO aircraft disinsection methods and procedures. Geneva: World Health Organization; 2021 (https://iris.who.int/handle/10665/339863, accessed 10 September 2024).

10. Dengue: global situation. Geneva: World Health Organization; 2023 (https://www.who.int/emergencies/disease-outbreak-news/item/2023-DON498, accessed 10 September 2024).

11. Chikungunya: key facts. Geneva: World Health Organization; 2022 (https://www.who.int/news-room/fact-sheets/detail/chikungunya, accessed 10 September 2024).

12. Public health risk assessment related to Western equine encephalitis (WEE) virus in the Region of the Americas: 23 February 2024 update. Pan American Health Organization; 2024 (https://www.paho.org/en/file/140273/download?token=WOw2H-6F, accessed 10 September 2024).

13. Zika virus: key facts. Geneva: World Health Organization; 2022 (https://www.who.int/news-room/fact-sheets/detail/zika-virus, accessed 10 September 2024).

14. Zika epidemiology update: February 2022. Geneva: World Health Organization; 2022 (https://www.who.int/publications/m/item/zika-epidemiology-update---february-2022, accessed 10 September 2024).

15. The history of Zika virus. Geneva: World Health Organization; 2016 (https://www.who.int/news-room/feature-stories/detail/the-history-of-zika-virus, accessed 10 September 2024).

16. Zika virus disease outbreak 2015–2016. Geneva: World Health Organization; 2016 (https://www.who.int/emergencies/situations/zika-virus-outbreak, accessed 10 September 2024).

17. WHO initiative to stop the spread of *Anopheles stephensi* in Africa: 2023 update. Geneva: World Health Organization; 2023 (https://iris.who.int/bitstream/handle/10665/372259/WHO-UCN-GMP-2023.06-eng.pdf?sequence=1, accessed 10 September 2024).

18. Pang AM, Gay S, Yadav R, Dolea C, Ponce C, Velayudhan R et al. The safety and applicability of synthetic pyrethroid insecticides for aircraft disinsection: a systematic review. Travel Med Infect Dis. 2020;33:101570. doi:10.1016/j.tmaid.2020.101570.

19. WHO handbook for guideline development, second edition. Geneva: World Health Organization; 2014 (https://apps.who.int/iris/handle/10665/145714, accessed 10 September 2024).

20. Aircraft disinsection insecticides. Environmental Health Criteria 243. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/100023, accessed 10 September 2024).

21. Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ. 2021;372:n71. doi:10.1136/bmj.n71.

22. Guyatt GH, Oxman AD, Vist GE, Kunz R, Falck-Ytter Y, Alonso-Coello P et al.; GRADE Working Group. GRADE: an emerging consensus on rating quality of evidence and strength of recommendations. BMJ. 2008;336(7650):924–6.

23. Guyatt G, Oxman AD, Akl EA, Kunz R, Vist G, Brozek J et al. GRADE guidelines: 1. Introduction – GRADE evidence profiles and summary of findings tables. J Clin Epidemiol. 2011;64(4):383–94. doi:10.1016/j.jclinepi.2010.04.026.

24. Atkins D, Best D, Briss PA, Eccles M, Falck-Ytter Y, Flottorp S et al. Grading quality of evidence and strength of recommendations. BMJ. 2004;328(7454):1490.

25. OCR.Space: Online OCR. OCR Space; 2023 (https://ocr.space/, accessed 10 September 2024).

26. Deep L Translator. Deep L; 2024 (https://www.deepl.com/translator, accessed 10 September 2024).

27. PDF Translator (GPT-4). OpenAI; 2024 (https://chatgpt.com/g/g-DTk1KpYjg-pdf-translator, accessed 10 September 2024).

28. Handbook on health inequality monitoring with a special focus on low- and middle-income countries. Geneva: World Health Organization; 2013 (https://iris.who.int/handle/10665/85345, accessed 10 September 2024).

29. Evidence to recommendations: methods used for assessing health equity and human rights considerations in COVID-19 and aviation. Interim guidance, 23 December 2020. Geneva: World Health Organization; 2020 (https://apps.who.int/iris/bitstream/handle/10665/338056/WHO-2019-nCoV-Aviation-evidence_equity-2020.1-eng.pdf?sequence=1&isAllowed=y, accessed 10 September 2024).

30. Checklist for systematic reviews and research syntheses. Joanna Briggs Institute (https://joannabriggs.org/ebp/critical_appraisal_tools, accessed 10 September 2024).

31. Guidelines for testing the efficacy of insecticide products used in aircraft. Geneva: World Health Organization; 2012 (https://iris.who.int/handle/10665/44836, accessed 10 September 2024).

32. Sullivan WN, Schoof HF, Maddock DR, Amyx CM, Porter JE. D-phenothrin, a promising new pyrethroid for disinsecting aircraft. J Med Entomol. 1974;11(2):231–3.

33. Berger-Preiss E, Koch W, Gerling S, Kock H, Klasen J, Hoffmann G et al. Aircraft disinsection: exposure assessment and evaluation of a new pre-embarkation method. Int J Hyg Environ Health. 2006;209(1):41–56.

34. Jakob WL, Maddock DR, Schoof HF, Porter JE. Gas-propelled aerosols and micronized dusts for control of insects in aircraft. 5. Effectiveness against insects of public health importance. J Econ Entomol. 1972;65(5):1454–8.

35. Ong O, Rigby L, Rasic G, Sly A, Devine G. An evaluation of the efficacy of aircraft disinsection procedures at Australian airports. Am J Trop Med Hyg. 2018;99(4):265–6.

36. Pimentel D, Klock JW. Disinsectization of aircraft by residual deposits of insecticides. Am J Trop Med Hyg. 1954;3(1):191–4.

37. Brooke JP, Evans M. Disinsection of aircraft with pressure packs containing the pyrethroids, resmethrin and bioresmethrin. Pesticide Science. 1971;2(4):133–7.

38. Cawley BM, Sullivan WN, Schechter MS, McGuire JU. Desirability of three synthetic pyrethroid aerosols for aircraft disinsection. Bull World Health Organ. 1974;51(5):537–40.

39. Langsford WA, Rajapaksa N, Russell RC. A trial [with *Culex pipiens fatigans* Wied.] to assess the efficacy of inflight disinsection of a Boeing 747 aircraft on the Singapore/Sydney sector. Pyrethrum Post. 1976;13:137–42.

40. Liljedhal LA, Retzer HJ, Sullivan WN, Schechter MS, Cawley BM, Morgan NO et al. Aircraft disinsection: the physical and insecticidal characteristics of (+) phenothrin applied by aerosol at “blocks away”. Bull World Health Organ. 1976;54:(4):391–6.

41. Russell RC, Rajapaksa N, Whelan PI, Langsford WA. Mosquito and other insect introductions to Australia aboard international aircraft, and the monitoring of disinsection procedures. In: Laird M, editor. Commerce and the spread of pests and disease vectors. New York, Praegar Scientific; 1984:109–41.

42. Sullivan WN, Keiding J, Wright JW. Studies on aircraft disinsection at “blocks away”. Bull World Health Organ. 1962;27(2):263–73.

43. Sullivan WN, Azurin JC, Wright JW, Gratz NG. Studies on aircraft disinsection at "blocks away" in tropical areas. Bull World Health Organ. 1964;30(1):113–8.

44. Sullivan WN, Pal R, Wright JW, Azurin JC, Okamoto R, McGuire JU et al. Worldwide studies on aircraft disinsection at "blocks away". Bull World Health Organ. 1972;46(4):485–91.

45. Sullivan WN, Hewing AN, Schechter MS, McGuire JU, Waters RM, Fields ES. Further studies of aircraft disinsection and odor characteristics of aerosols containing resmethrin and d-trans-resmethrin. Pest Control Science. 1975;40(1):5–13.

46. Sullivan WN, Cawley BM, Schechter MS, Hayes DK, Staker K, Pal R. A comparison of Freon- and water-based insecticidal aerosols for aircraft disinsection. Bull World Health Organ. 1978;56(1):129–32.

47. Russell RC, Paton R. In-flight disinsection as an efficacious procedure for preventing international transport of insects of public health importance. Bull World Health Organ. 1989;67(5):543–7.

48. Mackie FP, Crabtree HS. The destruction of mosquitoes in aircraft. Lancet. 1938;232(5999):447–50.

49. Jensen JA, Flury VP, Schoof HF. Dichlorvos vapour disinsection of aircraft. Bull World Health Organ. 1965;32(2):175–80.

50. Tew RP, David WAL, Busvine JR. Factors affecting the efficiency of aircraft disinsectisation procedures. Month Bull Min Health Emerg Pub Health Lab Serv. 1951;10:30–8.

51. Berger-Preiss E, Koch W, Behnke W, Gerling S, Kock H, Elflein L et al. In-flight spraying in aircrafts: determination of the exposure scenario. Int J Hyg Environ Health. 2004;207(5):419–30.

52. Maddock DR, Sedlak VA, Schoof HF. Preliminary tests with DDVP vapor for aircraft disinsection. Public Health Rep. 1961;76(9):777–80.

53. Smith PW, Mertens H, Lewis MF, Funkhouser GE, Higgins EA, Crane CR et al. Toxicology of dichlorvos at operational aircraft cabin altitudes. 1972;43(5):473–8.

54. Kilburn KH. Effects of onboard insecticide use on airline flight attendants. Arch Environ Health. 2004;59(6):284–91.

55. Wei B, Mohan KR, Weisel CP. Exposure of flight attendants to pyrethroid insecticides on commercial flights: urinary metabolite levels and implications. Int J Hyg Environ Health. 2012;215(4):465–73.

56. Bonta DM, Sutton P, Vergara X, Beckman J, Das R. Occupational illness among flight attendants due to aircraft disinsection. State of California Health and Human Services Agency, Department of Health Services; 2003.

57. Edmundson WF, Davies JE, Cranmer M. DDT and DDE in blood and DDA in urine of men exposed to 3 percent DDT aerosol. Public Health Rep. 1970;85(5):457–63.

58. Przyborowski T, Rychard J, Tyrakowski M. Dieldrin insecticide as a cause of an outbreak of intoxication on board of a ship. Przeglad Epidemiologiczny 1962;16(3):315–20.

59. Sutton PM, Vergara X, Beckman J, Nicas M, Das R. Pesticide illness among flight attendants due to aircraft disinsection. Am J Ind Med. 2007;50(5):345–56.

60. Woodyard C. Fliers fume over planes treated with pesticides. USA Today, 9 October 2001.

61. Vanden Driessche KS, Sow S, Van Gompel A, Vandeurzen K. Anaphylaxis in an airplane after insecticide spraying. J Travel Med. 2010;17(6):427–9.

62. Bitelli M. [Disinfection of airplanes]. Minerva Med. 1969;60(78):3672–81.

63. de Tavel F. Measures to be taken to prevent the transmission of *Aedes aegypti* by sea and air. Bull World Health Organ. 1967;36(4):639–44.

64. Whitfield D, Curtis CF, White GB, Targett GA, Warhurst DC, Bradley DJ. Two cases of falciparum malaria acquired in Britain. Br Med J (Clin Res Ed). 1984;289(6458):1607–9.

65. Carneiro de Mendonca F, Cerqueira NL. Insects and other arthropods captured by the Brazilian Sanitary Service on landplanes or seaplanes arriving in Brazil between January 1942 and December 1945. Bolet de la Oficina Sanitaria Panamericana (OSP). 1947;26(1)22–30.

66. Goh KT, Ng SK, Kumarapathy S. Disease-bearing insects brought in by international aircraft into Singapore. Southeast Asian J Trop Med Public Health. 1985;16(1):49–53.

67. O'Rourke EJ. The carriage of insects by aeroplanes with reference to the possible introduction of noxious insects into Ireland. [Unpublished report].

68. Laird M, Calder L, Thornton RC, Syme R, Holder PW, Mogiet M. Japanese *Aedes albopictus* among four mosquito species reaching New Zealand in used tires. J Am Mosq Control Assoc. 1994;10(1):14–23.

69. Sinitsyn SA. [Experience of protection against mosquitoes on a ship in the tropics]. Med Parazitol (Mosk). 1969;38(2):246–7.

70. Highton RB, van Someren EC. The transportation of mosquitos between international airports. Bull World Health Organ. 1970;42(2):334–5.

71. Russell RC. Survival of insects in the wheel bays of a Boeing 747B aircraft on flights between tropical and temperate airports. Bull World Health Organ. 1987;65(5):659–62.

72. Moreland SC. Malaria and international air travel. J R Soc Health. 1991;111(1):45372.

73. Derraik JGB. Exotic mosquitoes in New Zealand: a review of species intercepted, their pathways and ports of entry. Aust N Z J Public Health. 2004;28(5):433–44.

74. Sukehiro N, Kida N, Umezawa M, Murakami T, Arai N, Jinnai T et al. First report on invasion of yellow fever mosquito, *Aedes aegypti*, at Narita International Airport, Japan in August 2012. Jpn J Infect Dis. 2013;66(3):189–94.

75. Linthicum KJ, Kramer VL, Madon MB, Fujioka K; Surveillance-Control Team. Introduction and potential establishment of *Aedes albopictus* in California in 2001. J Am Mosq Control Assoc. 2003;19(4):301–8.

76. Mosquitoes infected with West Nile virus trapped at naval submarine base. The Day, 23 August 2019 (https://www.theday.com/local-news/20190823/mosquitoes-infected-with-west-nile-virus-trapped-at-naval-submarine-base, accessed 10 September 2024).

77. Pemberton CE. Insects carried in transpacific airplanes: a review of quarantine work prior to December 7, 1941, Honolulu. Personal communication from the Executive Entomologist, Experiment Station, Hawaiian Sugar Planters' Association. 1944.

78. Edwards JC. *Aedes aegypti* and other mosquito control measures in Port Sudan. J R Sanit Inst (Great Britain). 1949;69(6):718–20.

79. Thellier M, Lusina D, Guiguen C, Delamaire M, Legros F, Cicéron L et al. Is airport malaria a transfusion-transmitted malaria risk? Transfusion. 2001;41(2):301–2.

80. Moore CG, Francy DB, Eliason DA, Monath TP. *Aedes albopictus* in the United States: rapid spread of a potential disease vector. J Am Mosq Control Assoc. 1988;4(3):356–61.

81. Iyaloo DP, Zohdy S, Carney RM, Mosawa VR, Elahee KB, Munglee N et al. A regional One Health approach to the risk of invasion by *Anopheles stephensi* in Mauritius. PLoS Negl Trop Dis. 2024;18(9):e0011827.

82. Whitfield FGS. Air transport, insects and disease. Bull Ent Res. 1939;30(3):365–442.

83. Duguet J. Disinsectization of aircraft: study made in connection with the revision of international conventions. Bull World Health Organ. 1949;2(2):155–91.

84. Năstoiu I. [Air transport and dynamics of the reintroduction of malaria]. Rev Ig Bacteriol Virusol Parazitol Epidemiol Pneumoftiziol Bacteriol Virusol Parazitol Epidemiol. 1988;33(1):73–85.

85. Takahashi S. Survey on accidental introductions of insects entering Japan via aircraft. Commerce and the Spread of Pests and Disease Vectors. 1984;65–79.

86. Dethier VG. The transport of insects in aircraft. J Econ Entomol. 1945;38(5):528–31.

87. Danis M, Mouchet M, Giacomini T, Guillet P, Legros F, Belkaïd M. [Indigenous, introduced and airport malaria in Europe]. Med Mal Infect. 1996;26(Suppl. 3):393–6.

88. Le Maitre A, Chadee D. Arthropods collected from aircraft at Piarco International Airport, Trinidad, West Indies. Mosquito News. 1983;43(1):21–3.

89. Laird M. Insects collected from aircraft arriving in New Zealand during 1951. J Aviat Med. 1952;23(3):280–5.

90. Smith A, Carter ID. International transportation of mosquitoes of public health importance. In: Laird M, editor. Commerce and the spread of pests and disease vectors. New York, United States of America: Praeger Scientific. 1984:1–21.

91. Hughes JH. Aircraft and public health service: foreign quarantine entomology. Publ Hlth Rep Wash. 1949;(Suppl. 210):1–38.

92. Hedrich N, Bandolay M, Fischer J, Schlagenhauf P. Hunting for stowaway vectors on aircraft: the "Mosquito on Board" MOB project. Presented at the 9th Northern European Conference on Travel Medicine, 2024.

93. Karch S, Dellile MF, Guillet P, Mouchet J. African malaria vectors in European aircraft. Lancet. 2001;357(9251):235.

94. Hutchinson R, Bayoh N, Lindsay S. Risk of airport malaria in the United Kingdom. European Mosquito Bulletin. 2005;19:12–13.

95. Evans BR, Joyce CR, Porter JE. Mosquitoes and other arthropods found in baggage compartments of international aircraft. Mosq News. 1963;23:9–12.

96. Griffitts THD, Griffitts JJ. Mosquitoes transported by airplanes: staining method used in determining their importation. Pub Health Rep. 1931;46(47):2775–82.

97. Scholte EJ, Braks M, Schaffner F. Aircraft-mediated transport of *Culex quinquefasciatus*: a case report. Eur Mosq Bull. 2010;28:208–12.

98. Scholte EJ, Ibañez-Justicia A, Stroo A. Mosquito collections on incoming intercontinental flights at Schiphol International airport, the Netherlands, 2010–2011. J Eur Mosq Control Assoc. 2014;32:17–21.

99. Farrell E. The *Anopheles gambiae* problem in Brazil and West Africa 1941–44. Bulletin of the U.S. Army Medical Department. 1948;8(2):110–24.

100. Whittingham HE. Preventive medicine in relation to aviation. Proc R Soc Med. 1938;32(5):455–72.

101. Control of insect vectors in international air traffic: a survey of existing legislation. Geneva: World Health Organization; 1955 (https://iris.who.int/handle/10665/377018, accessed 10 September 2024).

102. Laird M. Insects collected from aircraft arriving in New Zealand from abroad. Zool Pub Vict Univ Coll, Wellington. 1951;11:1–30.

103. Welch EV. Insects found on aircraft at Miami, Florida, in 1938. Publ Hlth Rep Wash. 1939;54(14):561–6.

104. Laird M. Reactions of mosquitoes to the aircraft environment. T Proceed Roy Soc NZ. 1948;77(1):93–114.

105. Craven RB, Eliason DA, Francy DB, Reiter P, Campos EG, Jakob WL et al. Importation of Aede albopictus and other exotic mosquito species into the United States in used tires from Asia. J Am Mosq Control Assoc. 1988;4(2):138–42.

106. Charles LJ. Re-infestation problems in an *Aedes aegypti*-free area in British Guiana. West Indian Medical Journal. 1953;2(1).

107. Sinti-Hesse C, Díaz-Soria F, Casanova-Rojas W, Carey-Ángeles C, Tello-Espinoza R, Espinoza J et al. Embarcaciones fluviales como medio de dispersion de *Aedes aegypti* hacia zonas fronterizas de la amazonia peruana [River boats as a means of expansion of *Aedes aegypti* towards border zones of the Peruvian Amazon]. Rev Peru Med Exp Salud Publica. 2019;36(3):392–9.

108. Lewis DJ. General observations on mosquitoes with relation to yellow fever in the Anglo-Egyptian. Sudan Bull Entomol Res. 1947;37(4):543–66.

109. Joyce CR. Potentialities for accidental establishment of exotic mosquitoes in Hawaii. Proc Hawaiian Entomol Soc. 1961;17(3):403–13.

110. Lewis DJ. The Culicine mosquitos of Eritrea. Bull Ent Res. 1943;34:279–85.

111. Doughty E. Unwelcome insects in space. The Unconventional Gardener, 29 June 2020 (https://theunconventionalgardener.com/blog/unwelcome-insects-in-space, accessed 10 September 2024).

112. Cimerman S, Barata LC, Pignatari AC, Di Santi SM, Branquinho MS, Tubaki RM et al. Malaria transmission associated with airplane travel. Braz J Infect Dis. 1997;1(3):135–7.

113. Bakran-Lebl K, Camp JV, Kolodziejek J, Weidinger P, Hufnagl P, Cabal Rosel A et al. Diversity of West Nile and Usutu virus strains in mosquitoes at an international airport in Austria. Transbound Emerg Dis. 2022;69(4):2096–109.

114. D'Ambrosio G. The fight against domestic insects in the air-ports of Sicily. Rivista di medicina aeronautica. 1951;14(3):344–65.

115. Furumizo RT, Warashina WR, Savage HM. First collection of *Anopheles* (*Anopheles*) punctipennis (Say) on Oahu, Hawaii: implications for the potential introduction of West Nile virus. J Am Mosq Control Assoc. 2005;21(2):225–6.

116. Guillet P, Germain MC, Giacomini T, Chandre F, Akogbeto M, Faye O et al. Origin and prevention of airport malaria in France. Trop Med Int Health. 1998;3(9):700–5.

117. Ibañez-Justicia A, Gloria-Soria A, den Hartog W, Dik M, Jacobs F, Stroo A. The first detected airline introductions of yellow fever mosquitoes (*Aedes aegypti*) to Europe, at Schiphol International airport, the Netherlands. Parasit Vectors. 2017;10(1):603.

118. Laird M. Insect introduction hazards affecting Singapore and neighbouring territories. Medical J Malaya. 1956;11(1):40–62.

119. Larish LB, Savage HM. Introduction and establishment of *Aedes* (Finlaya) Japonicus japonicus (Theobald) on the island of Hawaii: implications for arbovirus transmission. J Am Mosq Control Assoc. 2005;21(3):318–21.

120. MacDonald WW. A mosquito survey at Kuala Lumpur airport with special reference to *Aedes aegypti*. Med J Malaya. 1956;10(3):232–45.

121. MacDonald WW. A resurvey of *Aedes aegypti* at Kuala Lumpur airport. Med J Malaya. 1959;13(2):179–86.

122. Holder P, George S, Disbury M, Singe M, Kean JM, McFadden A. A biosecurity response to *Aedes albopictus* (Diptera: Culicidae) in Auckland, New Zealand. J Med Entomol. 2010;47(4):600–9.

123. Lokossou AS, Aïkpon R, Razaki O, Tchabi A, Houémenou G. Mosquito surveillance in the seaport of Cotonou, Benin: monitoring of species diversity and assessment of susceptibility of mosquitoes to insecticides. J Commun Dis. 2023;55(4):80–5.

124. Wilke ABB, Vasquez C, Carvajal A, Moreno M, Petrie WD, Beier JC. Mosquito surveillance in maritime entry ports in Miami–Dade County, Florida to increase preparedness and allow the early detection of invasive mosquito species. PLoS One. 2022;17(4):e0267224.

125. Deblauwe I, Demeulemeester J, Sohier C, Van Loo T, De Witte J, Madder M et al. Invasive mosquito species surveillance in Belgium: towards a structural plan. Trop Med Int Health. 2017;22:17.

126. Murphy G, Vaux A, Medlock J. Challenges in undertaking mosquito surveillance at United Kingdom seaports and airports to prevent the entry and establishment of invasive vector species. Int J Environ Health Res. 2013;23(3):181–90.

127. Schmidt TL, Chung J, van Rooyen AR, Sly A, Weeks AR, Hoffmann AA. Incursion pathways of the Asian tiger mosquito (*Aedes albopictus*) into Australia contrast sharply with those of the yellow fever mosquito (*Aedes aegypti*). Pest Manag Sci. 2020;76(12):4202–9.

128. Vasquez MI, Notarides G, Meletiou S, Patsoula E, Kavran M, Michaelakis A et al. Two invasions at once: update on the introduction of the invasive species *Aedes aegypti* and *Aedes albopictus* in Cyprus – a call for action in Europe. Parasite. 2023;30:41.

129. Vaux AG, Murphy G, Baskerville N, Burden N. Monitoring for invasive and endemic mosquitoes at United Kingdom ports. European Mosquito Bulletin. 2011;29:133–140.

130. Scholte EJ, Schaffner F. Waiting for the tiger: establishment and spread of the *Aedes albopictus* mosquito in Europe. In: Takken W, Knols BG, editors. Emerging pests and vector-borne diseases in Europe, Volume 1. Wageningen, Kingdom of the Netherlands: Wageningen Academic Publishers. 2007:241–60.

131. Becker N, Schön S, Klein AM, Ferstl I, Kizgin A, Tannich E et al. First mass development of *Aedes albopictus* (Diptera: Culicidae): its surveillance and control in Germany. Parasitol Res. 2017;116(3):847–58.

132. O’Neill I. Mosquito survives in space for 18 months. Astroengine Com, 23 February 2009 (https://astroengine.com/2009/02/22/mosquito-survives-in-space-for-18-months, accessed 10 September 2024).

133. Giacomini T, Mouchet J, Mathieu P, Petithory JC. [Study of 6 cases of malaria acquired near Roissy-Charles-de-Gaulle in 1994: necessary prevention measures in airports]. Bull Acad Natl Med. 1995;179(2):335–51.

134. Giacomini T. [Malaria in airports and their neighbourhoods]. Rev Prat. 1998;48(3):264–7.

135. Van den Ende J, Lynen L, Elsen P, Colebunders R, Demey H, Depraetere K et al. A cluster of airport malaria in Belgium in 1995. Acta Clin Belg. 1998;53(4):259–63.

Annex 1. Countries and areas with aircraft disinsection regulations

Country	Regulation
The United States of America (arrival): Guidelines for Disinsection 2021: https://www.transportation.gov/airconsumer/spray.	
Ecuador[a]	Countries requiring the disinsection of all in-bound flights with an aerosolized spray while passengers are on board
Grenada	
Guyana	
India	
Kiribati	
Madagascar	
Panama	
Seychelles	
Timor-Leste	
Trinidad and Tobago	
United Republic of Tanzania (the)	
Uruguay	
Zimbabwe	
Australia	Countries requiring the disinsection of all in-bound flights but allowing the residual method of disinsection
Barbados	
Chile	
Cook Islands	
Fiji	
Jamaica	
New Zealand	
Czechia	Areas of contagious diseases
Egypt	Zika-affected countries
France	Areas of malaria, yellow fever and dengue fever
China, Hong Kong SAR	All incoming aircraft from Zika-affected countries designated as WHO Category 1 or Category 2
Indonesia	Areas affected by any sort of infectious or contagious disease[b]
Italy	All aircraft coming from areas affected by Zika virus transmission and areas where the *Aedes aegypti* carrier is present
Mauritius	Flights from African continent, Asia and subregions, the Middle East and islands of the Indian Ocean, and any other country where mosquito-borne diseases are prevalent
China, Macao SAR	Flights from areas of major infectious disease or Zika-affected countries
Palau	Non-United States carriers from Republic of Korea, China, Hong Kong SAR, China, Macao SAR and Thailand

Country	Regulation
Peru	Some in-country flights
Republic of Korea	30 countries, not including the United States
South Africa	Areas of malaria or yellow fever
Switzerland	Intertropical Africa
Taiwan, China	Incoming flights from areas with arbovirus vectors *Aedes aegypti* and *Ae. albopictus*
Thailand	Areas of yellow fever
United Kingdom of Great Britain and Northern Ireland	Malarial countries and countries with confirmed transmission of Zika (voluntary)
Canada (arrival*): Guidelines for Disinsection 2017: https://www.aircanada.com/ca/en/aco/home/plan/peace-of-mind/travel-tips.html#/home	
Australia	Pre-embarkation method (primary method): this method takes place without passengers or crew on board, and is performed or supervised by a certificate holder.
New Zealand	On-arrival method (alternate method): this method takes place before passengers have disembarked and the doors have been opened. Crew walk through the cabins discharging approved single-shot aerosols in the prescribed dosage.
Barbados	
Argentina (Buenos Aires)[c]	
Cuba	
Jamaica	Top of descent method: This method is similar to the "on-arrival method", except that it is carried out at the top of the aircraft's descent, just before it starts preparations for landing.
Martinique	
Saint Lucia[d]	
Saint Vincent and the Grenadines	
Chile (Santiago)[e]	
Trinidad and Tobago	

a. Only Galapagos and Interislands.

b. Indonesia is sensitive to infectious diseases due to population health and climate, which helps propagate infectious diseases such as severe acute respiratory syndrome and influenza from China, Middle East respiratory syndrome coronavirus (MERS-CoV) from the Middle East, and HIV from areas in Africa. See: Subiakto Y. Aviation medicine capacity on facing biological threat in Indonesia airports. Infectious Disease Reports. 2020;12(Suppl. 1):8738.

c. Spraying is required EZE–SCL before arriving in Santiago, Chile.

d. Spraying only required if flight transits at another destination before arrival.

e. Spraying is required YYZ–SCL before landing at Santiago, Chile, and SCL–EZE before the aircraft arrives at Buenos Aires, Argentina.

* Areas for which Top of Descent spraying prior to arrival is required include: Aruba, Guadeloupe, Puerto Rico, and Turks and Caicos Islands.

Annex 2. WHO-recommended aircraft cabin disinsection procedures [31]

Methods	Insecticide	Applied by whom	Applied when	Additional comments	Air conditioning
Pre-embarkation cabin treatment	Permethrin 2% aerosol at a rate of 35 g/100 m^3	Ground staff	Before embarkation of passengers, at the departing airport.	Should be performed in conjunction with cargo hold disinsection if cargo holds were not previously treated with residual spray.	Must be turned off during application of spray and for 5 mins after completion of spraying. Recirculation fans may be left on if essential for aircraft operation, but at lowest flow rate.
Pre-departure method	Aerosol of dphenothrin 2% or 1R-trans-phenothrin 2% at a rate of 35 g/100 m^3	Crew members	After passenger embarkation but before the overhead lockers are closed and the aircraft is pushed back for departure.	Should be performed in conjunction with cargo hold disinsection if cargo holds were not previously treated with residual spray. All areas of the aircraft cabin are sprayed, including flight deck, open overhead and coat lockers and toilets.	During disinsection and for 5 mins after completion of spraying, the aircraft's air conditioning should be set off or to normal flow, and recirculation fans must be on.
Pre-departure cargo hold disinsection	Single-shot aerosol can with a vertical ejection nozzle containing permethrin 2% and d-phenothrin 2% (or 1R-trans-phenothrin 2%) or an aerosol containing dphenothrin 2% or 1R-trans-phenothrin 2% at a rate of 35 g/100 m^3	Ground staff	Occurs at last departure airport after all cargo has been loaded and just before cargo hold door is closed. If small animals are to be loaded, should occur before animals are loaded but after all other cargo is on board.	Only applies if holds were not previously treated with residual spray.	Must remain off during disinsection and for 5 mins after completion of spraying; recirculation fans may be left on if essential but should be set to the lowest rate.

Methods	Insecticide	Applied by whom	Applied when	Additional comments	Air conditioning
On-arrival disinsection method	Aerosol of dphenothrin 2% or 1R-trans-phenothrin 2% at a rate of 35 g/100 m^3	Crew members	On arrival.	To be conducted if airline has not conducted one of the approved pre-arrival procedures, authorities at arrival airport are not satisfied that operator has used the chosen method correctly, or additional on-arrival treatment is required by authorities at arrival airport. All galleys, toilets, lockers, crew rest areas, and flight deck to be sprayed with a 5-min. saturation period to be observed.	Must remain off during disinsection and for 5 mins after completion of spraying; recirculation fans may be left on if essential but should be set to the lowest rate.
Residual treatment	Permethrin 2% EC at a rate of 0.2 g a.i./m^2 for internal surfaces, 0.5 g a.i./m^2 on floors	Trained, professional pest control operators	Every 8 weeks, when there are no passengers on board.	Residual treatment of the cabin should be performed in conjunction with cargo hold disinsection.	Must be turned off during treatment, but system and recirculation fans must be reactivated and run for at least 1 hour or in accordance with a.i. label guidance before passengers can embark the aircraft.

WHO *Guidelines for testing the efficacy of insecticide products used in aircraft (31)*

Annex 3. Disinsection regulations for marine and submarine conveyances

General ship regulations		
All vessels must obtain a ship sanitation control certificate or a ship sanitation control exception certificate every six months, as stated by the International Heath Regulations. This certificate should include the presence of any pest or insect as well as the method used to eradicate them from the vessel. If the certificate has expired or the vessel does not have one, the ship will undergo inspection and further disinsection in places specifically where vectors (such as mosquitoes and cockroaches) fester, as outlined by WHO *(1)*.		
Specific regulations		
Conveyance type	Country	Regulation
Ship	China	Yellow fever prevalent areas, including Nigeria, Peru, and Brazil ((except for Ceará, North Rio Grande, Texas, Paraiba, Pernambuco, Alagoas, Sergipe) *(2)*.
	Republic of Korea	Zika-affected countries: certificate must indicate used of pyrethroid ingredient in insecticide used for disinsection. Disinsection must occur at least 1 hour prior to departure from affected countries *(3)*.
	European Union countries	Ports in the European Union Member States to disinsect the imported goods at the port facilities *(4)*.

Note: European Union countries include Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands (Kingdom of the), Poland, Portugal, Romania, Slovakia, Slovenia, Spain and Sweden.

References

1. Ship Sanitation Certificate Program. Health Canada; 2009 [archived] (https://www.canada.ca/en/health-canada/services/healthy-living/travel-health/general-advice/ship-sanitation-certificate-program-health-canada.html, accessed 10 September 2024).

2. China: yellow fever prevention measures. Swedish Club; 2018 (https://www.swedishclub.com/news/loss-prevention/china-yellow-fever-prevention-measures/, accessed 10 September 2024).

3. Zika virus: South Korea requires self-disinfection certificates for vessels. Swedish Club; 2016 (https://www.swedishclub.com/news/loss-prevention/zika-virus-south-korea-requires-self-disinfection-certificates-for-vessels/, accessed 10 September 2024).

4. Interim guidance on maritime transport and Zika virus disease (https://www.shipsan.eu/Portals/0/docs/MaritimeZika_EUSHIPSAN_UPDATE_13.4.2016.pdf, accessed 10 September 2024).

Annex 4. Efficacy of aircraft disinsection checklist

Efficacy of Aircraft Disinsection Checklist

Section	Topic	No	Item	Adherence? (Y/N)
1. Studies of Aerosol Disinsection of Passenger Cabins	Recommended Placement of Cages:	1	Place cages in three areas of the main passenger cabin: middle row of seats, fifth row from the front, and fifth row from the rear.	
		2	In each area, place six cages (three on the left and three on the right side) in specific locations: foot space beneath the window seat, bottom cushion of the aisle seat, and middle of the open overhead luggage compartment.	
		3	Additional cages in at least one toilet area and one galley area.	
	Recommended Number of Mosquitoes Tested:	1	Use 25 non-blood-fed, 2–5-day-old female mosquitoes per cage.	
	Recommended Number of Experimental Replicates:	1	Conduct a minimum of two replicates with susceptible mosquito species.	
		2	Test on both single- and dual-aisle seating aircraft.	
	Environmental Conditions for Testing:	1	Air-conditioning should be switched off during spraying and outer door closed.	
		2	Maintain a temperature of 23°C ± 2°C during the test.	
	Assessment Methods:	1	Assess knock-down at 60 minutes and mortality after 24 hours.	

Section	Topic	No	Item	Adherence? (Y/N)
2. Studies of Aerosol Disinsection of Cargo Holds	Recommended Placement of Cages:	1	Place four cages on the floor near each corner of the cargo hold; and three cages evenly spaced along the central axis of the hold at a height of 1 meter.	
		2	Hang four additional cages 10 cm from the ceiling and walls in each corner and ensure the central axis placement of the cages is at a height of 1 meter.	
	Recommended Number of Mosquitoes Tested:	1	Use 25 non-blood-fed, 2–5-day-old female mosquitoes per cage.	
	Recommended Number of Experimental Replicates:	1	Conduct at least two replicates.	
	Environmental Conditions for Testing:	1	Use ambient climatic conditions.	
	Assessment Methods:	1	Assess knock-down at 60 minutes and mortality after 24 hours.	
3. Studies of Long-term Residual Activity in Passenger Cabins	Recommended Placement of Cages:	1	Evaluate with a minimum of three representative internal aircraft surfaces (e.g., AerFilm®, carpet, curtains, wall panels).	
	Recommended Number of Mosquitoes Tested:	1	Use 10 non-blood-fed, susceptible female mosquitoes aged 2–5 days per WHO cone.	
	Recommended Number of Experimental Replicates:	1	Conduct three replicates from separately reared batches per location.	
	Environmental Conditions for Testing:	1	Maintain 27°C ± 2°C and 80% ± 10% relative humidity.	
	Assessment Methods:	1	Conduct WHO cone bioassays 24 hours after spraying and then at regular intervals (e.g., weekly) until mortality drops below 80%.	

Section	Topic	No	Item	Adherence? (Y/N)
4. Timing of Disinsection	Pre-flight Spraying:	1	Apply aerosol by ground staff before passengers board, not more than 1 hour before doors are closed.	
		2	Use aerosol containing insecticide with rapid action and limited residual action.	
	Blocks-away:	1	Spray conducted by crew after passengers board and before take-off.	
		2	Air-conditioning should be switched off during spraying.	
	Top-of-descent:	1	Apply aerosol as the aircraft starts its descent.	
		2	Use aerosol containing insecticide for rapid action.	
	Residual Application:	1	Apply by professional pest control operators for long-term residual activity on aircraft interior surfaces.	
		2	Evaluate residual surface treatments weekly until mortality drops below 80%.	
5. General Guidelines	Cage Specifications:	1	Dimensions: Cylindrical steel-frame cages with a diameter of 90 mm and height of 150 mm.	
		2	Material: Nylon or polyester mesh netting with hole openings of 1.2 x 1.2 mm to 1.6 x 1.6 mm.	
		3	Placement: Cages should be positioned properly labeled (e.g., position of exposure, date of test) to ensure traceability and accurate interpretation of results.	
	Positive Control Inclusion:	1	Include a positive control (e.g., permethrin and D-phenothrin) in laboratory tests.	
	Mortality Thresholds for Control Groups:	1	If mortality in the control group exceeds 20%, the test is rejected.	
		2	If mortality in the control group is 0–20%, use Abbott's formula to correct the results with treated samples.	
	Data Analysis:	1	Analyze dose-response relations and determine the lethal dosage (LD50, LD90) using log-dose probit regression.	
		2	Report results with confidence intervals and correct mortality rates using Abbott's formula if necessary.	
6. Cited Rational for Non-Adherence				

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