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ORIGINAL RESEARCH

Diversity and distribution of mosquitoes (Diptera: Culicidae) in Peru and their relationship with metaxenic diseases

Diversidad y distribución de mosquitos (Diptera: Culicidae) en el Perú y su relación con las enfermedades metaxénicas

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Abstract

Introduction: Tropical Andean and Amazonian ecosystems shape the great biodiversity found in Peru. However, studies on mosquitoes (Diptera: Culicidae) in the country are scarce, resulting in an information gap regarding their diversity, ecology, distribution, and abundance.
Objective: To search for documented evidence on the diversity and distribution of mosquitoes (Diptera: Culicidae) in Peru, and to establish —in relation to species of medical relevance— their potential link with the epidemiological cycle of some metaxenic diseases.
Materials and methods: A literature review was conducted in Google Scholar, ScienceDirect, PubMed, and SciELO, as well as in 7 databases specialized in insect taxonomy, using specific terms and their combinations by means of Boolean operators ("AND" and "OR"). Search strategy: study types: original research articles, review articles, books, and book chapters; publication period: no initial date - June 2020; languages: English, Spanish, and Portuguese.
Results: A total of 99 studies were retrieved after the initial search, 84 in the 4 electronic databases and 15 in the specialized databases, of which 41 met the inclusion criteria. One additional record was included due to its relevance to the objective of the review. The studies included were original articles (n=28), review articles (n=6), books (n=5), book chapters (n=2), and undergraduate theses (n=1). Regarding the language of publication, 25 (59.52%) were published in English and 17 (40.48%) in Spanish.
Conclusions. In Peru, the greatest diversity of mosquito genera is found in the departments of Loreto, Huánuco, and Madre de Dios. Knowledge of the diversity of mosquitoes in Peru that have the potential to cause health issues is relatively scarce and is focused on *Aedes aegypti* and some species of the *Anopheles* and *Culex* genera, thus overlooking a rich diversity distributed in the Amazonian forests, high jungle, and inter-Andean valleys.

Resumen

Introducción. Los ecosistemas tropicales andinos y amazónicos determinan la gran biodiversidad presente en Perú. Sin embargo, los estudios sobre mosquitos (Diptera: Culicidae) en el país son escasos, lo que resulta en un vacío de información en cuanto a su diversidad, ecología, distribución y abundancia.
Objetivos. Buscar evidencia documentada sobre la diversidad y la distribución de mosquitos en el Perú, y establecer —con relación a las especies de importancia médica— su potencial vínculo con el ciclo epidemiológico de algunas enfermedades metaxénicas.
Materiales y métodos. Se realizó una revisión de la literatura en Google Académico, ScienceDirect, PubMed y Scielo, así como en siete bases de datos especializadas en taxonomía de insectos, usando términos específicos y diferentes combinaciones con operadores booleanos ("AND" y "OR"). Estrategia de búsqueda: tipos de estudios: artículos originales de investigación, artículos de revisión, libros y capítulos de libros; periodo de publicación: sin límite inicial a junio del 2020; idiomas: inglés, español y portugués.
Resultados. La búsqueda inicial arrojó 99 estudios, 84 en las 4 bases de datos electrónicas y 15 en las bases de datos especializadas, de los cuales 41 cumplieron los criterios de inclusión. También se incluyó un registro adicional debido a su relevancia con el objetivo de la revisión. Los estudios incluidos fueron artículos originales (n=28), artículos de revisión (n=6), libros (n=5), capítulos de libro (n=2) y tesis de pregrado (n=1). Respecto al idioma de publicación, 25 (59.52%) estaban en inglés y 17 (40.48%), en español.
Conclusiones. En Perú, la mayor diversidad de géneros de mosquitos se encuentra presente en los departamentos de Loreto, Huánuco y Madre de Dios. El conocimiento sobre la diversidad de mosquitos en Perú que tienen el potencial de generar problemas de salud es relativamente escaso y se centra en el Aedes aegypti y algunas especies de los géneros Anopheles y Culex, dejando de lado una rica diversidad distribuida en los bosques amazónicos, la selva alta y los valles interandinos.

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Introduction

Insects are the most abundant and diverse group of arthropods, and although it is estimated that there are between 3 and 10 million species, at least 70% have not yet been described or identified,[1,2] especially in tropical rainforests where there is greater entomological diversity, with the Neotropics being the region with the most information gaps.[3-5] The vegetation cover of tropical forests, the complexity of the existing habitats and the variety of ecological niches in these ecosystems are the main factors that favor such a great diversity and abundance of insects, since the lower the degree of disturbance in forest areas, the greater the number of these species.[6,7]

Anthropogenic activities are the main threat to the conservation of mosquito diversity, mainly in the Neotropics, as they reduce the number of species as a result of habitat destruction due to landscape fragmentation, pesticide use, introduction of invasive species and, ultimately, climate change.[3,8] The consequences of human activities have a serious impact on megadiverse countries such as Peru, Colombia and Brazil, where many species disappear because of the impact of these activities before they can be discovered or described by scientists.[9-14]

The family Culicidae (Diptera) is divided into two subfamilies, Anophelinae (482 species) and Culicinae (3 119 species)[15] and groups together nearly 3 500 species and subspecies of mosquitoes (distributed in 42 genera),[14,16,17] a number that is constantly increasing because of their importance for human and veterinary medicine and because these organisms are widely studied.[16] The Neotropical region has the greatest diversity of mosquitoes because it is home to 31% of the total number of known species in the world (1 069/3 492).[17]

Similarly, the Culicidae family comprises wild and anthropogenic species that are highly adaptable to human-modified ecosystems and are very likely to transmit pathogens such as arboviruses, which cause dengue, chikungunya, and yellow fever; nematodes, which cause lymphatic filariasis; and protozoa, which cause malaria.[13,16]

On the other hand, it has been shown that the diversity of mosquitoes classified as vectors is significantly higher in the fractions colonized by humans than in climax fractions of an ecosystem.[6] In addition, it has been reported that anthropogenic alterations of ecosystems, e.g., changes in land use, may disrupt such diversity, which in turn can affect the transmission dynamics of emerging and re-emerging zoonotic infectious diseases.[11]

In this sense, and in order to prevent new outbreaks of arboviral and parasitic diseases in anthropogenic environments, it is recommended to conserve old-growth forest in tropical rainforests,[12] since deforestation, agriculture, urban development and human encroachment into undisturbed areas are considered catalysts to changes in disease vector dominance and the introduction of new pathogens.[6]

Table 1 summarizes the number of mosquito genera and species reported in some South American countries in the Walter Reed Biosystematics Unit's systematic catalog of the family Culicidae,[18] as well as the expected record of species by country reported in the Smithsonian Institution's VectorMap.[19]

Research on mosquito diversity in natural, urban, and disturbed environments may reveal unknown ecological and epidemiological characteristics useful in the design of vector control and surveillance strategies, which is what has been least investigated in Peru.[20,21] In this regard, in Peru, the lack of research, the few internal entomological reports from the Ministry of Health on the diversity of mosquitoes reported after the declaration of epidemiological outbreaks of dengue, yellow fever, Zika, chikungunya, and malaria,[22,23] and the emergence of data on new species, all point to the lack of information and poor understanding of the diversity, distribution, abundance, ecology, bionomics, capacity, and vectorial competence of these insects.[22-25]

Table 1. Numerical values of mosquito genera and species reported in South American countries and expected record.

Countries	Number of genera and species (WRBU)[18]		Expected species record (VM)[19]
	No. of genera	No. species	
Argentina	22	217	872
Bolivia	22	191	1 593
Brazil	23	478	6 648
Chile	5	19	139
Colombia	23	340	4 333
Ecuador	24	223	3 453
Paraguay	16	120	543
Peru	20	181	437
Venezuela	23	290	5 175
Total	24 *	787 *	NA

WRBU: Walter Reed Biosystematics Unit; VM: VectorMap; NA: Not applicable.
* Total number of genera and species reported in South America.
Source: Own elaboration.

According to the Peru Weekly Epidemiological Bulletin for the epidemiological week 53-2020,[23] in 2020, the highest number of dengue cases were recorded in the departments of Ucayali (n=10 934), Loreto (n=10 829), Ica (n=7 126), San Martín (n=6 640), and Junín (n=4 256), accounting for 70.54% of cases nationwide. For that same year, the highest number of Zika cases was recorded in San Martín (n=45) and Loreto (n=43),[26] while chikungunya was most prevalent in Piura with 80 cases, and San Martín with 42 cases.[27] As for malaria, the department with the highest number of cases reported was Loreto (n=13 112), followed by Amazonas (n=1 549), and Junín (n=528).[28]

The main reason for conducting studies on insect vectors in urban and/or urban-rural settings in most countries of the world has always been the collection of epidemiological evidence following the appearance of a disease or the detection of these insects in risk areas.[29-31] Based on these considerations, the objectives of the present literature review were to search for documented evidence on the diversity and distribution of mosquitoes in Peru, and to establish —in relation to medically relevant species— their potential link with the epidemiological cycle of some metaxenic diseases.

Materials and methods

A literature review was conducted in Google Scholar, ScienceDirect, PubMed, and SciELO using the following search strategy: type of study: research articles, review articles, books, and book chapters on diversity and distribution of mosquitoes in Peru and their possible link with the epidemiological cycle of some metaxenic diseases; publication period: no initial date until June 2020; publication language: English, Spanish, and Portuguese; search terms in English: "Mosquitoes of the Neotropics and Peru," "Species list," "Vector disease of Peru," "Culicid fauna of Peru," and "Diversity and distribution," and search terms in Spanish: "Mosquitos del Neotrópico y Perú," "Listado de especies," "Enfermedad vectorial del Perú," "Culicidofauna del Perú," and "Diversidad y distribución," which were combined with the Boolean connectors "AND" and "OR" to establish the search equations.

Likewise, taking into account the research question, a combination of Boolean operators was used to provide specificity to the search. Thus, in the general search equation, the terms, and their equivalent in English, "Mosquitos del Neotrópico y Perú," "Listado de especies," "Enfermedad vectorial del Perú," "Culicidofauna del Perú," and "Diversidad

y distribución" OR " Culicidofauna del Perú" were used alone or combined, through the "AND" operator, with the terms "Listado de especies" OR "Enfermedad vectorial del Perú" OR "Diversidad y distribución."

The citations and titles of the studies retrieved from the search engines, together with their abstracts, were included in a Microsoft Excel spreadsheet to eliminate duplicate references.

Similarly, using the same search criteria mentioned above, seven electronic databases specialized in insect taxonomy were consulted to identify studies on mosquitoes in Peru. These databases were Global Biodiversity Information Facility,[32] Integrated Taxonomic Information System,[33] Mosquito Taxonomic Inventory,[34] Systematic Catalog of Culicidae,[18] The Ecological Register,[35] Smithsonian Institution,[19] and WoRMS.[36]

Once the initial searches were conducted, publications that did not match the eligibility criteria, were not of interest to the review, and did not meet the following inclusion criteria were excluded: record of mosquito species in Peru, vector research on mosquitoes and pathogens in Peru, and study on genera and species of Neotropical mosquitoes on diversity and distribution of Peruvian mosquitoes and on mosquito-borne metaxenic diseases in Peru. The research included an additional record (undergraduate thesis)[37] identified through other sources, which in the authors' opinion complements the information recorded.

In order to ensure reproducibility of the literature review, two of the investigators conducted the searches independently and selected the scientific literature to be included for full analysis. Disagreements were resolved by consensus.

The data taken from the publications included in this literature review were the following: general information (title, abstract, name of the journal in which the article was published, and year of publication), department of Peru where the study was conducted, and species of mosquito identified; the latter was ordered based on the taxonomic category of genus.

Results

The initial search yielded 99 results, 84 (84.85%) from electronic databases and 15 (15.15%) from specialized databases, of which 48 were eliminated because they were duplicates and 10 because they did not match the eligibility criteria or were not relevant to the objective of the study. Thus, 42 studies were included for full analysis, 41 (97.62%) from the literature searches and 1 (2.38%) additional study identified in the references of the selected articles. Figure 1 below presents the flowchart for the screening and information search process.

Of the 42 studies included, there were 28 original articles, 6 review articles, 5 books, 2 book chapters, and 1 undergraduate theses; 11 (26.19%) were published between 1934 and 2000, and 31 (73.81%) between 2001 and 2020; 25 (59.52%) were published in English, 17 (40.48%) in Spanish, and no articles were found in Portuguese.

Of the journal articles, most were published in the Revista Peruana de Medicina Experimental y Salud Pública (n=7) and the Journal of Medical Entomology (n=4). The others were distributed in multiple journals.

The list of mosquito species of Peru prepared based on this review (Table 2) indicates that the greatest diversity of genera is found in the departments of Loreto (17 genera), Huánuco (15 genera) and Madre de Dios (10 genera), followed by Cusco, San Martín, Ucayali and Junín (with 6 to 7 genera); in the rest of the departments, less than 5 genera were found, consisting mainly of *Anopheles, Aedes,* and *Culex.*

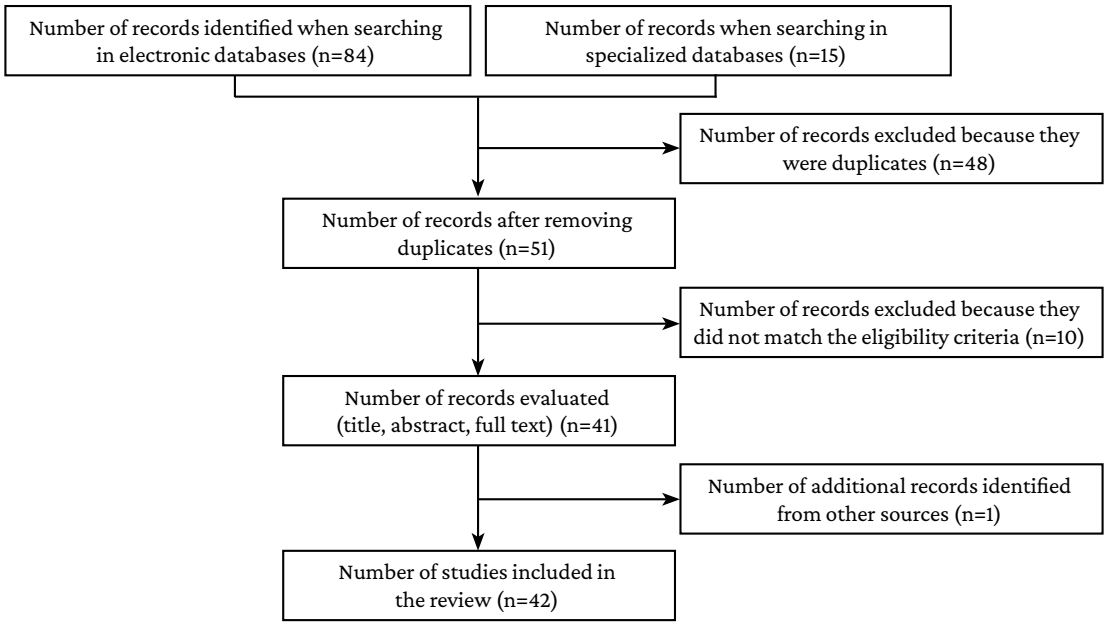

Figure 1. Flowchart of the search and selection of studies.
Source: Own elaboration.

Table 2. List of the species of Culicidae mosquitoes recorded in Peru.

Author, year	Department (number of species recorded)	Taxon
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	Amazonas (n=6)	*Anopheles albitarsis* Lynch-Arribalzaga, 1878; *Anopheles fluminensis* Root, 1927; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.*, 1940.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Heinemann & Belkin[41] 1979		*Culex quinquefasciatus* Say, 1823.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	Ancash (n=5)	*Anopheles albimanus* Wiedemann, 1821; *Anopheles calderoni* Wilkerson, 1991; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles punctimacula* Dyar & Knab, 1906.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	Apurímac (n=4)	*Anopheles eiseni* Coquillet, 1902; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles triannulatus* Neiva & Pinto, 1922.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971 Calderón *et al.*[39]1995	Arequipa (n=4)	*Anopheles pseudopunctipennis* Theobald, 1901.
Morales-Ayala[38] 1971 Belkin *et al.*[42] 1968 González *et al.*[43] 2016		*Culex apicinus* Philippi, 1865; *Culex debilis* Dyar & Knab, 1914 (=*apicinus* auct).
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	Ayacucho (n=12)	*Anopheles bambusicolus* Komp, 1937; *Anopheles boliviensis* Theobald, 1905; *Anopheles cruzii* Dyar & Knab, 1908; *Anopheles eiseni* Coquillet, 1902; *Anopheles fluminensis* Root, 1927; *Anopheles oswaldoi* Peryassu, 1922; *Anopheles parvus* Chagas, 1907; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.*, 1940; *Anopheles tibiamaculatus* Neiva, 1906; *Anopheles triannulatus* Neiva & Pinto, 1922.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971, Calderón *et al.*[39] 1995 Heinemann & Belkin[41] 1979	Cajamarca (n=12)	*Anopheles albimanus* Wiedemann, 1821; *Anopheles albitarsis* Lynch-Arribalzaga, 1878; *Anopheles argyritarsis* Robineau-Desvoidy, 1827; *Anopheles fluminensis* Root, 1927; *Anopheles intermedius* Chagas, 1908; *Anopheles oswaldoi* Peryassu, 1922; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.*, 1940; *Anopheles triannulatus* Neiva & Pinto, 1922.
Morales-Ayala[38] 1971		*Culex quinquefasciatus* Say, 1823.
Morales-Ayala[38] 1971 Cabezas *et al.*[40] 2015 Belkin *et al.*[42] 1968 Troyes *et al.*[44] 2006		*Aedes aegypti* Linnaeus, 1762; *Aedes taeniorhynchus* Wiedemann, 1821.

Table 2. List of the species of Culicidae mosquitoes recorded in Peru. (continued)

Author, year	Department (number of species recorded)	Taxon
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Kirchgatter *et al.*[45] 2020	Cusco (n=30)	*Anopheles argyritarsis* Robineau-Desvoidy, 1827; *Anopheles benarrochi* Gabaldón *et al.,* 1941; *Anopheles boliviensis* Theobald, 1905; *Anopheles cruzii* Dyar & Knab, 1908; *Anopheles darlingi* Root, 1926; *Anopheles eiseni* Coquillet, 1902; *Anopheles fluminensis* Root, 1927; *Anopheles homunculus* Komp, 1937; *Anopheles laneanus* Correa & Cerqueira, 1944; *Anopheles lepidotus* Zavortink, 1973; *Anopheles lutzi* Cruz, 1901; *Anopheles mediopunctatus* Theobald, 1903; *Anopheles peryassui* Dyar & Knab, 1908; *Anopheles pholidotus* Zavortink, 1973; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.,* 1940; *Anopheles tibiamaculatus* Neiva, 1906; *Anopheles triannulatus* Neiva & Pinto, 1922.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Harbach & Howard[46] 2009		*Chagasia bonneae Root, 1927.*
Morales-Ayala[38] 1971		*Culex allostigma* Howard *et al.,* 1915; *Culex coronator* Dyar & Knab, 1906; *Culex mollis* Dyar & Knab, 1906.
Morales-Ayala[38] 1971		*Sabethes belisarioi* Neiva, 1908.
Morales-Ayala[38] 1971		*Trichoprosopon compressurn* Lutz, 1905; *Trichoprosopon digitatum* Rondani, 1848; *Trichoprosopon pallidiventer* Lutz, 1905
Morales-Ayala[38] 1971 Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762; *Aedes condolescens* Dyar & Knab, 1907; *Aedes scapularis* Rondani, 1848; *Aedes serratus* Theobald, 1901.
Morales-Ayala[38] 1971	Distribution unknown (n=2)	*Culex usquatissimus* Dyar, 1922; *Culex usquatus* Dyar, 1918.
Calderón *et al.*[39] 1995	Huancavelica (n=3)	*Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.,* 1940.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	Huánuco (n=35)	*Anopheles benarrochi* Gabaldón *et al.,* 1941; *Anopheles mediopunctatus* Theobald, 1903; *Anopheles neomaculipalpus* Curry, 1931; *Anopheles oswaldoi* Peryassu, 1922; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.,* 1940.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Harbach & Howard[46] 2009		*Chagasia bonneae* Root, 1927.
Morales-Ayala[38] 1971		*Coquillettidia juxtamansonia* Chagas, 1907; *Coquillettidia lynchi* Shannon, 1931; *Coquillettidia venezuelensis* Theobald, 1912.
Morales-Ayala[38] 1971		*Culex allostigma* Howard *et al.,* 1915; *Culex archegus* Dyar, 1929; *Culex corniger* Theobald, 1903; *Culex declarator* Dyar & Knab, 1906; *Culex habilitator* Dyar & Knab, 1906; *Culex mollis* Dyar & Knab, 1906; *Culex urichii* Coquillett, 1906.
Morales-Ayala[38] 1971		*Psorophora (Grabhamia) cingulata* Fabricius, 1805; *Psorophora (Janthinosoma) ferox* von Humboldt, 1819; *Psorophora (Janthinosoma) lutzii* Theobald, 1901.
Morales-Ayala[38] 1971		*Haemagogus capricornii* Lutz, 1904.
Morales-Ayala[38] 1971		*Limatus flavisetosus* de Oliveira-Castro, 1935; *Limatus pseudomethysticus* Bonne-Wepster & Bonne, 1920.
Morales-Ayala[38] 1971		*Mansonia pseudotitillans* Theobald, 1901; *Mansonia titillans* Walker, 1848.
Morales-Ayala[38] 1971		*Johnbelkinia longipes* Fabricius, 1805.
Morales-Ayala[38] 1971		*Sabethes belisarioi* Neiva, 1908.
Morales-Ayala[38] 1971		*Toxorhynchites bambusicola* Lutz & Neiva 1913; *Toxorhynchites haemorrhoidalis* Fabricius, 1787.
Morales-Ayala[38] 1971		*Trichoprosopon pallidiventer* Lutz, 1905.
Morales-Ayala[38] 1971		*Uranotaenia geometrica* Theobald, 1901.
Morales-Ayala[38] 1971		*Wyeomyia aporonoma* Dyar & Knab, 1906.
Morales-Ayala[38] 1971 Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762; *Aedes fulvus* Wiedemann, 1828; *Aedes serratus* Theobald, 1901.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Belkin *et al.*[42] 1968	Ica (n=5)	*Anopheles calderoni* Wilkerson, 1991; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles punctimacula* Dyar & Knab, 1906.
Morales-Ayala[38] 1971 Belkin *et al.*[42] 1968 González *et al.*[43] 2016		*Culex quinquefasciatus* Say, 1823.

Table 2. List of the species of Culicidae mosquitoes recorded in Peru. (continued)

Author, year	Department (number of species recorded)	Taxon
Cabezas *et al.*[40] 2015	Ica (n=5)	*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Belkin *et al.*[42] 1968 Harrison *et al.*[47] 2012	Junín (n=23)	*Anopheles benarrochi* Gabaldón *et al.,* 1941; *Anopheles dunhami* Causey, 1945 (=*trinkae*); *Anopheles eiseni* Coquillet, 1902; *Anopheles fluminensis* Root, 1927; *Anopheles intermedius* Chagas, 1908; *Anopheles lepidotus* Zavortink, 1973; *Anopheles nuneztovari* Gabaldon, 1940; *Anopheles oswaldoi* Peryassu, 1922; *Anopheles parvus* Chagas, 1907; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.,* 1940; *Anopheles tibiamaculatus* Neiva, 1906; *Anopheles triannulatus* Neiva & Pinto, 1922.
Calderón *et al.*[39] 1995		*Chagasia bonneae* Root, 1927; *Chagasia fajardi* Lutz, 1904
Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979 Belkin *et al.*[42] 1968		*Culex archegus* Dyar, 1929; *Culex bihaicola* Dyar & Núñez-Tovar, 1927; *Culex mollis* Dyar & Knab, 1906; *Culex putumayensis* Matheson, 1934.
Morales-Ayala[38] 1971		*Sabethes belisarioi* Neiva, 1908.
Morales-Ayala[38] 1971		*Trichoprosopon digitatum* Rondani, 1848.
Morales-Ayala[38] 1971		*Wyeomyia aphobema* Dyar, 1918.
Morales-Ayala[38] 1971 Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Heinemann & Belkin[41] 1979 Belkin *et al.*[42] 1968	La Libertad (n=9)	*Anopheles albimanus* Wiedemann, 1821; *Anopheles calderoni* Wilkerson, 1991; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles punctimacula* Dyar & Knab, 1906.
Morales-Ayala[38] 1971 Heinemann & Belkin[41]		*Culex erraticus* Dyai & Knab, 1906; *Culex quinquefasciatus* Say, 1823; *Culex nigripalpus* Theobald, 1901.
Morales-Ayala[38] 1971 Cabezas *et al.*[40] 2015 Heinemann & Belkin[41] 1979		*Aedes aegypti* Linnaeus, 1762; *Aedes scapularis* Rondani, 1848.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	Lambayeque (n=6)	*Anopheles albimanus* Wiedemann, 1821; *Anopheles calderoni* Wilkerson, 1991; *Anopheles eiseni* Coquillet, 1902; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles punctimacula* Dyar & Knab, 1906.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Belkin *et al.*[42] 1968, Iannacone *et al.*[48] 2000	Lima y Callao (n=8)	*Anopheles calderoni* Wilkerson, 1991; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles punctimacula* Dyar & Knab, 1906; *Aedes taeniorhynchus* Wiedemann, 1821.
Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979 Belkin *et al.*[42] 1968 Iannacone *et al.*[48] 2000		*Culex debilis* Dyar & Knab, 1914 (=*apicinus* auct); *Culex diplophyllum* Dyar, 1929; *Culex quinquefasciatus* Say, 1823.
Cabezas *et al.*[40] 2015 Iannacone *et al.*[48] 2000		*Aedes aegypti* Linnaeus, 1762.

Table 2. List of the species of Culicidae mosquitoes recorded in Peru. (continued)

Author, year	Department (number of species recorded)	Taxon
Johnson *et al.*[12] 2008 Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Belkin *et al.*[42] 1968 Heinemann & Belkin[41] 1979 Prussing *et al.*[49] 2019	Loreto (n=152)	*Anopheles* (Stethomyia) undetermined; *Anopheles acanthotorynus* Komp, 1937; *Anopheles albitarsis* Lynch-Arribalzaga, 1878; *Anopheles argyritarsis* Robineau-Desvoidy, 1827; *Anopheles bambusicolus* Komp, 1937; *Anopheles benarrochi* Gabaldón *et al.,* 1941; *Anopheles boliviensis* Theobald, 1905; *Anopheles costai* Fonseca & Ramos, 1939; *Anopheles cruzii* Dyar & Knab, 1908; *Anopheles darlingi* Root, 1926; *Anopheles dunhami* Causey, 1945 (=*trinkae*); *Anopheles eiseni* Coquillet, 1902; *Anopheles evansae* Brethes, 1926 (=*noroestensis*); *Anopheles fluminensis* Root, 1927; *Anopheles forattinii* Wilkerson & Sallum, 1999; *Anopheles homunculus* Komp, 1937; *Anopheles intermedius* Chagas, 1908; *Anopheles intermedius* Peryassu, 1908; *Anopheles kompi* Edwards, 1930; *Anopheles konderi* Galvao & Damasceno, 1942; *Anopheles mattogrossensis* Lutz & Neiva, 1911; *Anopheles mediopunctatus* Theobald, 1903; *Anopheles neivai* Howard *et al.,* 1913; *Anopheles neomaculipalpus* Curry, 1931; *Anopheles nimbus* Theobald, 1902; *Anopheles nuneztovari* Gabaldon, 1940; *Anopheles oswaldoi* Peryassu, 1922; *Anopheles peryassui* Dyar & Knab, 1908; *Anopheles pseudomaculipes* Peryassu, 1922; *Anopheles rangeli* Gabaldón *et al.,* 1940; *Anopheles shannoni* Davis, 1931; *Anopheles* sp. Meigen, 1818; *Anopheles squamifemur* Antunes, 1937; *Anopheles strodei* Root, 1926; *Anopheles thomasi* Shannon, 1933; *Anopheles triannulatus* Neiva & Pinto, 1922.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Harbach & Howard[46] 2009		*Chagasia bonneae* Root, 1927.
Johnson *et al.*[12] 2008 Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971		*Coquillettidia albicosta* Peryassu, 1908; *Coquillettidia nigricans* Coquillett, 1904; Coquillettidia arribalzagae Theobald, 1903; *Coquillettidia hermanoi* Lane & Coutinho, 1940; *Coquillettidia juxtamansonia* Chagas, 1907; *Coquillettidia lynchi* Shannon, 1931; *Coquillettidia venezuelensis* Theobald, 1912.
Johnson *et al.*[12] 2008 Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979 Rosero-García *et al.*[50] 2017		*Culex adamesi* Sirivanakam & Galindo, 1980; *Culex allostigma* Howard *et al.,* 1915; *Culex amazonensis* Lutz, 1905; *Culex bastagarius* Dyar & Knab, 1906; *Culex bonnei* Dyar, 1921; *Culex caudelli* Dyar &Knab, 1906; *Culex conservator* Dyar & Knab, 1906; *Culex corniger* Theobald,1903; *Culex coronator* Dyar & Knab, 1906; *Culex declarator* Dyar &Knab, 1906; *Culex distinguendus* Dyar, 1928; *Culex dunni* Dyar, 1918; *Culex eastor* Dyar, 1920; *Culex elongatus* Rozeboom & Komp, 1950; *Culex evansae* Root, 1927; *Culex gnomatos* Mureb-Sallum *et al.,*1997; *Culex infoliatus* Bonne-Wepster & Bonne, 1919; *Culex intrincatus* Brèthes, 1916; *Culex isabelae* Duret, 1968; *Culex mollis* Dyar & Knab, 1906; *Culex nigripalpus* Theobald, 1901; *Culex ocossa* Dyar & Knab, 1919; *Culex olimpioi* Xavier & Silva Mattos, 1970; *Culex pedroi* Sirivanakarn & Belkin, 1980; *Culex pilosus* Dyar & Knab, 1906; *Culex portesi* Senevet & Abonnenc, 1941; *Culex putumayensis* Matheson, 1934; *Culex quinquefasciatus* Say, 1823; *Culex serratimarge* Root, 1927; *Culex* sp.1 Linnaeus, 1758; *Culex* sp.2 Linnaeus, 1758; *Culex* sp.3 Linnaeus, 1758; *Culex spissipes* Theobald, 1903. *Culex* spp. Linnaeus, 1758; *Culex stonei* Lane & Whitman, 1943; *Culex taeniopus* Dyar & Knab, 1907; *Culex theobaldi* Lutz, 1904; *Culex urichii* Coquillett, 1906; *Culex vomerifer* Komp, 1932.
Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971 Belkin *et al.*[42] 1968		*Haemagogus anastasionis* Dyar, 1921; *Haemagogus baresi* Cerqueira, 1960; *Haemagogus capricornii* Lutz, 1904; *Haemagogus janthinomys* Dyar, 1921; *Haemagogus* sp. Williston, 1896; *Haemagogus* sp. (small Colombian form); *Haemagogus spegazzinii* Brethes, 1912 (=*uriartei*).
Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971		*Johnbelkinia longipes* Fabricius, 1805.
Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979		*Limatus durhamii* Theobald, 1901; *Limatus flavisetosus* de Oliviera Castro, 1935; *Limatus asulleptus* Theobald, 1903; *Limatus* sp. Theobald, 1901.
Johnson *et al.*[12] 2008 Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979		*Mansonia amazonensis* Theobald, 1901; *Mansonia flaveola* Coquillett, 1906; *Mansonia humeralis* Dyar & Knab, 1916; *Mansonia indubitans* Dyar & Shannon, 1925; *Mansonia pseudotitillans* Theobald, 1901; *Mansonia* spp. Blanchard, 1901; *Mansonia titillans* Walker, 1848.
Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971		*Orthopodomyia fascipes* Coquillett, 1905
Johnson *et al.*[12] 2008 Need *et al.*[30] 1993, Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971		*Psorophora albigenu* Peryassu, 1908; *Psorophora cilipes* Fabricius, 1805; *Psorophora (Grabhamia) cingulata* Fabricius, 1805; *Psorophora (Janthinosoma) ferox* von Humboldt, 1819; *Psorophora lineata* Humboldt, 1819; *Psorophora (Janthinosoma) lutzii* Theobald, 1901; *Psorophora (Janthinosoma) albipes* Theobald, 1907; *Psorophora (Janthinosoma) circumflava* Cerqueira, 1943; *Psorophora (Janthinosoma) cyanescens* Coquillett, 1902; *Psorophora (Janthinosoma) lanei* Shannon & Cerqueira, 1943.

Table 2. List of the species of Culicidae mosquitoes recorded in Peru. (continued)

Author, year	Department (number of species recorded)	Taxon
Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979	Loreto (n=152)	*Sabethes amazonicus* Gordon & Evans, 1922; *Sabethes belisarioi* Neiva, 1908; *Sabethes chloropterus* Humboldt, 1819; *Sabethes cyaneus* Fabricius, 1805; *Sabethes quasicyaneus* Peryassu, 1922; *Sabethes tarsopus* Dyar & Knab, 1908.
Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Heinemann & Belkin[41] 1979		*Toxorhynchites haemorrhoidalis* Fabricius, 1787; *Toxorhynchites* sp. Theobald, 1901.
Need *et al.*[30] 1993 Pecor *et al.*[31] 2000		*Trichoprosopon digitatum* Rondani, 1848
Johnson *et al.*[12] 2008 Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971		*Uranotaenia apicalis* Theobald, 1903; *Uranotaenia calosomata* Dyar & Knab, 1907; *Uranotaenia geometrica* Theobald, 1901; *Uranotaenia hystera* Dyar & Knab, 1913; *Uranotaenia lowii* Theobald, 1901; *Uranotaenia nataliae* Lynch-Arribalzaga, 1891; *Uranotaenia pallidoventer* Theobald, 1903; *Uranotaenia pulcherrima* Lynch-Arribalzaga, 1891; *Uranotaenia socialis* Theobald, 1901; *Uranotaenia* spp. Lynch-Arribálzaga, 1891.
Johnson *et al.*[12] 2008 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979		*Wyeomyia aphobema* Dyar, 1918; *Wyeomyia aporonoma* Dyar & Knab, 1906; *Wyeomyia flui* Bonne-Wepster & Bonne, 1920; *Wyeomyia pseudopecten* Dyar & Knab, 1906; *Wyeomyia ulocoma* Theobald, 1903.
Johnson *et al.*[12] 2008 Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Rios-Araujo[37] 2015 Morales-Ayala[38] 1971 Cabezas *et al.*[40] 2015 Fernández *et al.*[51] 2005		*Aedes fulvus* Wiedemann, 1828; Aedes (Howardina) lorraineae Berlin, 1969; *Aedes aegypti* Linnaeus, 1762; *Aedes albopictus* Skuse, 1894; *Aedes angastivittatus* Dyar & Knab, 1907; *Aedes argyrothorax* Bonne-Wepster & Bonne, 1920; *Aedes condolescens* Dyar & Knab, 1907; *Aedes fulvithorax* Lutz, 1904; *Aedes fulvus* Wiedemann, 1828; *Aedes hastatus* Dyar, 1922; *Aedes hortator* Marks, 1907; *Aedes leei* Berlin, 1969; *Aedes leucocelaenus* Dyar & Shannon, 1924; *Aedes serratus* Theobald, 1901.
Johnson *et al.*[12] 2008 Need *et al.*[30] 1993 Pecor *et al.*[31] 2000 Morales-Ayala[38] 1971		*Aedeomyia squamipennis* Lynch-Arribalzaga, 1878.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Radocy & Chaboo[52] 2014	Madre de Dios (n=36)	*Anopheles albimanus* Wiedemann, 1821; *Anopheles albitarsis* Lynch-Arribalzaga, 1878; *Anopheles argyritarsis* Robineau-Desvoidy, 1827; *Anopheles benarrochi* Gabaldón *et al.,* 1941; *Anopheles darlingi* Root, 1926; *Anopheles dunhami* Causey, 1945 (=*trinkae*); *Anopheles eiseni* Coquillet, 1902; *Anopheles evansae* Brethes, 1926 (=*noroestensis*); *Anopheles fluminensis* Root, 1927; *Anopheles galvaoi* Causey *et al.,* 1943; *Anopheles mattogrossensis* Lutz & Neiva, 1911; *Anopheles mediopunctatus* Theobald, 1903; *Anopheles nuneztovari* Gabaldon, 1940; *Anopheles oswaldoi* Peryassu, 1922; *Anopheles peryassui* Dyar & Knab, 1908; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.,* 1940; *Anopheles shannoni* Davis, 1931; *Anopheles* sp. Meigen, 1818; *Anopheles triannulatus* Neiva & Pinto, 1922.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Harbach & Howard46 2009		*Chagasia bonneae Root, 1927.*
Radocy & Chaboo[52] 2014		*Coquillettidia* spp. Dyar, 1905.
Radocy & Chaboo[52] 2014		*Culex corniger* Theobald, 1903; *Culex* sp. Linnaeus, 1758; *Culex* spp. Linnaeus, 1758.
Radocy & Chaboo[52] 2014		*Lutzia* sp. Theobald, 1903.
Radocy & Chaboo[52] 2014		*Mansonia humeralis* Dyar & Knab, 1916; *Mansonia indubitans* Dyar & Shannon, 1925; *Mansonia titillans* Walker, 1848; *Mansonia wilsoni* Barreto & Coutinho, 1944.
Radocy & Chaboo[52] 2014		*Ochlerotatus* spp. Lynch-Arribalzaga, 1891.
Radocy & Chaboo[52] 2014		*Uranotaenia calosomata* Dyar & Knab, 1907; *Uranotaenia geometrica* Theobald, 1901.
Radocy & Chaboo[52] 2014 Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762; *Aedes fulvus* Wiedemann, 1828.
Radocy & Chaboo[52] 2014		*Aedeomyia squamipennis* Lynch-Arribalzaga, 1878.
Morales-Ayala[38] 1971, Calderón *et al.*[39] 1995	Moquegua (n=2)	*Anopheles pseudopunctipennis* Theobald, 1901.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.

Table 2. List of the species of Culicidae mosquitoes recorded in Peru. (continued)

Author, year	Department (number of species recorded)	Taxon
Calderón *et al.*[39] 1995	Pasco (n=11)	*Anopheles eiseni* Coquillet, 1902; *Anopheles mediopunctatus* Theobald, 1903; *Anopheles nuneztovari* Gabaldon, 1940; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.,* 1940; *Anopheles triannulatus* Neiva & Pinto, 1922.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971		*Culex urichii* Coquillett, 1906.
Morales-Ayala[38] 1971		*Psorophora (Grabhamia) cingulata* Fabricius, 1805.
Belkin *et al.*[42] 1968		*Trichoprosopon digitatum* Rondani, 1848.
Morales-Ayala[38] 1971		*Wyeomyia aphobema* Dyar, 1918.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Heinemann & Belkin[41] 1979	Piura (n=10)	*Anopheles albimanus* Wiedemann, 1821; *Anopheles calderoni* Wilkerson, 1991; *Anopheles eiseni* Coquillet, 1902; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles punctimacula* Dyar & Knab, 1906.
Heinemann & Belkin[41] 1979 Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762; *Aedes scapularis* Rondani, 1848.
Heinemann & Belkin[41] 1979		*Culex erraticus* Dyai & Knab, 1906; *Culex interrogator* Dyar & Knab, 1906; *Culex nigripalpus* Theobald, 1901.
Calderón *et al.*[39] 1995	Puno (n=5)	*Anopheles argyritarsis* Robineau-Desvoidy, 1827; *Anopheles eiseni* Coquillet, 1902; *Anopheles rangeli* Gabaldón *et al.,* 1940; *Anopheles squamifemur* Antunes, 1937.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	San Martín (n=19)	*Anopheles albitarsis* Lynch-Arribalzaga, 1878; *Anopheles argyritarsis* Robineau-Desvoidy, 1827; *Anopheles benarrochi* Gabaldón *et al.,* 1941; *Anopheles braziliensis* Chagas, 1907; *Anopheles eiseni* Coquillet, 1902; *Anopheles fluminensis* Root, 1927; *Anopheles intermedius* Chagas, 1908; *Anopheles mediopunctatus* Theobald, 1903; *Anopheles oswaldoi* Peryassu, 1922; *Anopheles peryassui* Dyar & Knab, 1908; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles rangeli* Gabaldón *et al.,* 1940; *Anopheles triannulatus* Neiva & Pinto, 1922.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995 Harbach & Howard[46] 2009		*Chagasia bonneae* Root, 1927.
Morales-Ayala[38] 1971		*Culex quinquefasciatus* Say, 1823.
Morales-Ayala[38] 1971		*Psorophora albipes* Theobald, 1907; *Psorophora albigenu* Peryassú, 1908.
Morales-Ayala[38] 1971		*Limatus pseudomethysticus* Bonne-Wepster & Bonne, 1920
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	Tacna (n=2)	*Anopheles pseudopunctipennis* Theobald, 1901.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.
Morales-Ayala[38] 1971 Calderón *et al.*[39] 1995	Tumbes (n=17)	*Anopheles albimanus* Wiedemann, 1821; *Anopheles albitarsis* Lynch-Arribalzaga, 1878; *Anopheles apicimacula* Dyar y Knab, 1906; *Anopheles argyritarsis* Robineau-Desvoidy, 1827; *Anopheles calderoni* Wilkerson, 1991; *Anopheles eiseni* Coquillet, 1902; *Anopheles pseudopunctipennis* Theobald, 1901; *Anopheles punctimacula* Dyar & Knab, 1906; *Anopheles triannulatus* Neiva & Pinto, 1922.
Calderón *et al.*[39] 1995 Harbach & Howard[46] 2009		*Chagasia bonneae Root, 1927.*
Morales-Ayala[38] 1971		*Culex interrogator* Dyar & Knab, 1906; *Culex nigripalpus* Theobald, 1901.
Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979		*Deinocerites pseudes* Dyar & Knab, 1909.
Heinemann & Belkin[41] 1979		*Psorophora confinnis* Lynch-Arribalzaga, 1891.
Morales-Ayala[38] 1971 Heinemann & Belkin[41] 1979 Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762; *Aedes scapularis* Rondani, 1848; *Aedes taeniorhynchus* Wiedemann, 1821.

Table 2. List of the species of Culicidae mosquitoes recorded in Peru. (continued)

Author, year	Department (number of species recorded)	Taxon
Calderón *et al.*[39] 1995	Ucayali (n=14)	*Anopheles argyritarsis* Robineau-Desvoidy, 1827; *Anopheles benarrochi* Gabaldón *et al.,* 1941; *Anopheles evansae* Brethes, 1926 (=*noroestensis*); *Anopheles fluminensis* Root, 1927; *Anopheles mattogrossensis* Lutz & Neiva, 1911; *Anopheles mediopunctatus* Theobald, 1903; *Anopheles neomaculipalpus* Curry, 1931; *Anopheles nuneztovari* Gabaldon, 1940; *Anopheles oswaldoi* Peryassu, 1922; *Anopheles peryassui* Dyar & Knab, 1908; *Anopheles rangeli* Gabaldón *et al.,* 1940; *Anopheles squamifemur* Antunes, 1937; *Anopheles triannulatus* Neiva & Pinto, 1922.
Cabezas *et al.*[40] 2015		*Aedes aegypti* Linnaeus, 1762.

Source: Own elaboration.

Discussion

Mosquitoes of Peru: overview

The first studies on insects of medical relevance in Peru were carried out at the beginning of the 20th century and began in 1913 *with* the discovery and description of *Lutzomyia verrucarum, the* vector of the Peruvian wart, by Charles H. T. Townsend.[53]

The first explorations of the Culicidae fauna were conducted in the Peruvian Amazon region, where 11 species of the genus *Mansonia* were described; they were collected between March and June 1931 in the border between Brazil and Peru. These explorations also allowed for the development of a dichotomous key for the American species of the subgenus *Mansonia*.[54]

More than three decades after no studies on mosquitoes had been carried out, in 1968, Belkin *et al.*[42] published one of the first lists of these species in Peru and other South American countries, in which they reported five genera (*Aedes*, *Anopheles*, *Culex*, *Haemagogus,* and *Trichoprosopon)* with 10 identified species, and included other Diptera genera such as *Corethrella* (Corethrellidae), *Dixella* (Dixidae) and *Lutzomiops* (synonymous with *Corethrella*; Corethrellidae).

The largest list of mosquitoes in Peru was published by Morales-Ayala[38] in 1971, who obtained records from the National Malaria Eradication Service, an institution that was part of the Ministry of Health from 1957 to 1973. In that list, the researcher reported the presence of 18 mosquito genera (Anophelinae: *Chagasia* and *Anopheles*; Culicinae: *Toxorhynchites, Trichoprosopon, Runchomyia, Wyeomyia, Limatus, Sabethes, Coquillettidia, Mansonia, Uranotaenia, Orthopodomyia, Aedeomyia, Psorophora, Aedes, Haemagogus, Culex,* and *Deinocerites*), in addition to 5 other Diptera genera: *Corethrella, Lutzomiops, Sayomyia* (currently listed as a subgenus of *Chaoborus*), *Chaoboridae,* and *Edwardsops* (currently listed *as a subgenus* of *Chaoborus, Chaoboridae,* and *Dixella)*. Morales-Ayala[38] also documented 70 species of mosquitoes in the department of Loreto and 20 in the Iquitos area.

The first isolates of eastern encephalitis arboviruses in the Amazon region of Peru were reported by Scherer *et al.*[55] in 1975, in a study in which they also established that, as this region grows and human and equine populations increase, diseases caused by these viruses may become a serious threat to public health. Later, in 1979, Heinemann & Belkin[41] also reported the presence of 10 genera in the Peruvian Amazon: *Aedes*, *Anopheles*, *Culex*, *Deinocerites*, *Limatus*, *Mansonia*, *Psorophora*, *Sabethes*, *Trichoprosopon*, and *Wyeomyia*, with 18 recognized species and 10 with an uncertain identification.

Subsequently, in a 1993 study in which a mosquito trapping program was initiated to evaluate the potential for arbovirus transmission in the Peruvian Amazon, Need *et al.*[30] collected more than 35 000 mosquito specimens of 13 genera (*Aedeomyia*, *Aedes*, *Anopheles*, *Coquillettidia*, *Culex*, *Haemagogus*, *Limnatus*, *Mansonia*, *Psorophora*, *Sabethes*, *Toxorhynchites*,

Trichoprosopon, and *Uranotaenia*) and reported that at least 25 of these species were found in urban and jungle sites in the Iquitos area.

The latter findings, together with those of Morales-Ayala,[38] Heinemann & Belkin[41] and Belkin *et al.*,[42] were at the time the best reported lists of Peruvian mosquitoes and the first evidence of this type for the Peruvian Amazon. Years later, Calderón *et al.*[39] updated the list of *Anopheles* species in Peru (they recorded 43 species, 7 of which were new,) determined their distribution and importance in malaria transmission, and established that 10 species were possible vectors of *Plasmodium*.

In a study focused on the search for arboviruses in the Amazon region of Iquitos, Pecor *et al.*[31] identified 16 genera, 30 subgenera, and 96 species of mosquitoes, of which 24 species were new records in Peru. Similarly, other research has focused on the geographic distribution and seasonal fluctuations of *Anopheles* (e.g., *Anopheles darlingi*, vector of the protozoan *Plasmodium falciparum*) and on certain arboviruses in 3 Amazonian departments.[56-59]

Furthermore, in order to understand how land use change affects species composition in a gradient of anthropogenic influence, Jhonson *et al.*[12] collected 15 107 mosquito specimens in the Peruvian Amazon, belonging to 10 genera and 48 species. In that study, the authors demonstrated that the type of land use significantly influences mosquito diversity and that *Culex quinquefasciatus* was the most abundant species, comprising 63% of the collections in urban sites and 90% of the collections in peri-urban sites.

In turn, the capture and collection of mosquitoes of medical relevance in Puerto Maldonado (Madre de Dios) made by Radocy & Chaboo[52] allowed the identification of 9 mosquito genera: *Aedeomyia*, *Aedes*, *Anopheles*, *Coquilletidia*, *Culex*, *Lutzia*, *Mansonia*, *Ochlerotatus*, and *Uranotaenia*, with 9 taxa at species level being recognized in that same work, thus classifying many samples in the genus and/or subgenus category due to the lack of taxonomic keys.

Similarly, some research on the presence and distribution of *A. aegypti* in Peru conducted after the occurrence of viral processes associated with dengue in different departments of the country led to the development of several studies related to the vector, its spatial distribution, the characteristics of the habitat in which it develops, and the vector control measures to be implemented,[40,53-55] which allowed establishing that the occurrence of dengue was associated with the presence of *A. albopictus* in Loreto and that, consequently, there was an entomological risk.[37]

Some unpublished observations on mosquitoes in the Apurimac River valley (departments of Ayacucho and Cusco) that were included in internal institutional documents (e.g., of the Ministry of Health) report the finding of species such as *Limatus durhami*, *Mansonia* sp., *Culex* spp., Cx. *quinquefasciatus*, *Psorophora cingulata*, *Uranotaenia* spp., *Coquillettidia* spp., *Psorophora dimidiate,* and *Anopheles pseudopunctipennis.* These studies subsequently revealed the presence of *A. aegypti,* as well as species of *Haemagogus* spp. and *Sabethes* spp.

Diversity and distribution of mosquitoes (Diptera: Culicidae) in Peru

Of the 41 mosquito genera documented worldwide,[13,14,16,18] 24 (58.5%) have been reported in South America, among them *Aedomyia*, *Aedes* (which includes, among others, the subgenera *Georgecraigius*, *Howardina*, *and Ochlerotatus*), *Anopheles*, *Chagasia*, *Coquillettidia*, *Culex*, *Deinocerites*, *Galindomyia*, *Haemagogus*, *Isostomyia*, *Johnbelkinia*, *Lutzia*, *Limatus*, *Mansonia*, *Onirion*, *Orthopodomyia*, *Psorophora* (comprising the subgenera *Janthinosoma* and *Grabhamia, which are* considered by Morales-Ayala[38] as genera), *Runchomyia*, *Sabethes*, *Shannoniana*, *Toxorhynchites*, *Trichoprosopon*, *Uranotaenia*, and *Wyeomyia* (which includes *Phoniomyia* as a subgenus).[18]

The consolidated list of mosquitoes of Peru includes 20 recognized genera (48.7% of the world total): *Aedomyia*, *Aedes* (which includes *Ochlerotatus* as a subgenus), *Anopheles*, *Chagasia*, *Coquillettidia*, *Culex*, *Deinocerites*, *Haemagogus*, *Johnbelkinia*, *Lutzia*, *Limatus*, *Mansonia*, *Onirion*, *Orthopodomyia*, *Psorophora*, *Sabethes*, *Toxorhynchites*, *Trichoprosopon*, *Uranotaenia,* and *Wyeomyia,* which represent a total of 181 species records recognized in the systematic catalog of the family Culicidae of the Walter Reed Biosystematics Unit[18] (Table 1). The genus *Runchomyia* is not included in this database because its presence has not been confirmed in the country, although it should be noted that Morales-Ayala[38] inadequately described three species of this genus: *R. hyperleucum* (Martini, 1931) (currently known as: *Trichoprosopon (Runchomyia)* lost species), *R. leucopus* (Dyar and Knab, 1906) (currently known as: *Johnbelkinia leucopus*, not recorded in Peru), and *R. longipes* (Fabricius, 1805) (currently known as: *Johnbelkinia longipes* with records in Peru).[18,60]

The physiographic, topographic, altitudinal, and climatic characteristics of Peru have generated diverse environments in the territory that are favorable for the presence of numerous arthropods of medical relevance, which have allowed the circulation of pathogenic agents that cause diseases in humans and wildlife,[61] generating areas with greater diversity and a high degree of endemism.[62,63]

As mentioned above, the inventory of the 181 species of mosquitoes present in Peru was initiated in the 1930s,[54] but it was between the 1970s and 1990s when the list of species increased, especially after the detection of new arboviruses in wild populations of mosquitoes present in urban or peri-urban geographic environments of the Amazon rainforest and in the jungle areas of several departments of the country; these data have been complemented with the updating of the taxonomic inventory of species of the genus *Anopheles* (Table 2).[30,38-42,55]

At present, few contributions have improved the knowledge of the diversity of mosquitoes in Peru, mainly after the epidemics of dengue, Zika, chikungunya, yellow fever, Oropouche fever, and malaria in several departments of the country, which involve *A. aegypti* mosquitoes and several species of *Anopheles* as their main vectors.

Of all the species of the Culicidae family known in the world, more than 150 belong to the genera *Anopheles*, *Culex*, *Aedes*, and *Haemagogus*, which are largely accountable for the high morbidity and mortality in humans due to diseases such as malaria, dengue, encephalitis, filariasis, chikungunya, Zika, yellow fever, among others.[14,17,29,48,64-66] However, despite its significance in public health and extensive history of studies, the knowledge about this family is far from being comprehensive.

Megadiverse countries such as Brazil, Colombia and Peru are facing an alarming destruction of their natural ecosystems due to anthropogenic activities, land use change, the dramatic decrease in forest cover, and habitat degradation. Although these situations put at risk, and even reduce, biological diversity by causing the extinction of multiple species that in many cases have not been discovered and described yet, they are a favorable scenario for insect communities of medical relevance to find food sources (mainly human) and transmit pathogens that circulate in wild animals such as mammals, birds, amphibians, reptiles and arthropods, thereby increasing the risk of transmission of zoonotic diseases.[9-11,67,68]

Conclusions

In Peru, 181 species and 20 genera of mosquitoes (*Aedomyia*, *Aedes*, *Anopheles*, *Chagasia*, *Coquillettidia*, *Culex*, *Deinocerites*, *Haemagogus*, *Johnbelkinia*, *Lutzia*, *Limatus*, *Mansonia*, *Onirion*, *Orthopodomyia*, *Psorophora*, *Sabethes*, *Toxorhynchites*, *Trichoprosopon*, *Uranotaenia, and Wyeomyia)* have been recorded, most of them in the departments of Loreto (17 genera), Huánuco (15 genera), and Madre de Dios (10 genera).

The known species in the country account for less than 42% of the 437 expected records, so it can be concluded that knowledge about the diversity of mosquitoes in Peru that have the potential to cause health issues is relatively scarce and is focused on *A. aegypti* and some species of the genera *Anopheles* and *Culex*, excluding a rich diversity distributed in the Amazonian forests, the high jungle, and the inter-Andean valleys. This is particularly critical because ecosystem health surveillance, vector control, and understanding of new epidemiological scenarios of metaxenic disease occurrence are essential for public health.

Conflicts of interest

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