Review Article

A SYNOPSIS OF TAXONOMIC DATA ON THE EXTANT SPECIES OF MOSQUITOES IN INDIA, WITH AN ANNOTATED NOTE ON ADDITIONAL TAXA DESCRIBED AFTER TYAGI (2020)

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ABSTRACT

A total of 412 extant species and subspecies of mosquitoes (Diptera: Culicidae) classified under 50 genera and three subfamilies from India are synoptically discussed. Annotations on taxonomic status of a few taxa are also made with a view to settle their position. This paper describes the historical background of varied researches on Indian mosquitoes with their major resource museums and repositories in the country.

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INTRODUCTION

The present work is an attempt to highlight taxonomic scenario of the mosquitoes in India. It also offers taxonomic annotations on certain species of interest to culicidologists and/or vector-borne disease specialists.

Mosquitoes are true flies belonging to the Family Culicidae that comprise a monophyletic taxon under the Order Diptera (Phylum Arthropoda). Generally characterized as slender, long-legged insects that are easily recognized by their long proboscis and the presence of scales on most parts of the body, they constitute a large family with 3,578 species that occurs throughout temperate and tropical regions worldwide.[1,2] In India, a world famous megadiversity with a humongous variety in ecosystems, mosquitoes occur in abundance in all the States and Union Territories but least explored in its tropical forest environments such as those in the north-eastern regions of lower Himalaya, and the Eastern and Western Ghat regions in the peninsular India.[3,4,5] All three subfamilies, viz., Anophelinae, Toxorhynchitinae and Culicinae, are comprehensively represented by 12 Tribes, 50 genera, 43 subgenera and 412 species which accounts for more than 11% of the world taxa (Table 1). Aedini (Subfamily Culicinae) with 175 species (including *Aedes aegypti* and *Ae. albopictus* – the deadly vectors of dengue, yellow fever, chikungunya and Zika virus etc.) is the richest among all the tribes. On the other hand, Culicini (Subfamily Culicinae), the second most taxa-rich tribe, comprises an extraordinary diverse range of vectors for different diseases such as human lymphatic filariasis (*Culex quinquefasciatus*), Japanese encephalitis (*Cx. tritaeniorhynhus, Cx. gelidus, Cx. pseudovishnui*), West Nile Virus (*Cx. quinquefasciatus, Cx. tritaeniorhynchus, Cx. vishnui, Cx. bitaeniorhynchus and Cx. univittatus*). It is interesting that Brugian filariasis (caused by the parasite *Brugia malayi*), rampant in Kerala State, is transmitted by the mosquitoes belonging to Tribe Mansoniini (Subfamily Culicinae). The Tribe Anophelini has all the human malaria vectors; a total of eleven mosquito species that are capable to transmit the pathogen, though only six of them are primary vectors (*An. culicifacies, An. dirus, An. fluviatilis, An. minimus, An. sundaicus* and *An. stephensi*). Besides, some are of

local importance, viz. *An. philippinensis-nivipes, An. varuna, An. annularis, An. subpictus* and *An. jeyporiensis*.[6] In India the Subfamily Anophelinae is represented by only single Tribe, Anophelini, comprising two subgenera, namely, Anopheles and Cellia, under the genus Anopheles. All the malaria vector species are classified under Cellia only.[7]

Table 1. Indian mosquito species arranged under Subfamilies, Tribes, Genera and Subgenera

SUBFAMILY **Tribe**	**No. of Genera**	**No. of Subgenera**	**No. of species**
ANOPHELINAE			
Anophelini	1	2	64
TOXORHYNCHITINAE			
Toxorhynchitini	1	1	9
CULICINAE			
Aedeomyiini	1	1	5
Aedini	34	18	175
Culicini	2	8	85
Culisetini	1	2	3
Ficalbiini	2	3	7
Hodgesiini	1	0	2
Mansoniini	2	2	7
Orthopodomyiini	1	0	5
Sabethini	3	4	16
Uranotaeniini	1	2	34
	50	**43**	**412** (incl. a subspecies)

Close to 40 species of mosquitoes are vectors for the diseases like malaria, lymphatic filariasis, dengue, chikungunya, Zika, Japanese encephalitis, West Nile virus etc., while many others are vicious biters that leave behind a characteristic 'wheel' which is itchy and painfully inflammatory, besides being a source of allergy and annoyance (Table 2).

Table 2. Distribution of mosquito-borne diseases of public health importance in India and the world

Diseases (Pathogens)	Vectors	Distribution	
		World	India
Malaria *Plasmodium falciparum, P, vivax, P. ovale, P.malariae and P. knowlesi)*	*Anopheles* spp.	Tropics, main burden Sub-Saharan Africa	Throughout; more pronounced in eastern and north-eastern Indian States
Lymphatic Filariasis *Wuchereria bancrofti Brugia malayi, B. timori*	*Culex quinquefasciatus* and *Mansonia* spp.	Tropical urban areas	Mostly peninsular States; *W. bancrofti* is predominant, while *B. malayi* is restricted mainly to Kerala. *B timori* absent.
Dengue DENV 1-4	*Aedes aegypti* and *Ae. albopictus*	Urban tropics	Throughout India
Chikungunya CHIKV	*Aedes aegypti* and *Ae. albopictus*	Urban tropics	Throughout India
Yellow Fever YFV	*Aedes aegypti*	Africa, Central & Southern Americas; recently sporadic imported cases occurred in Asia	Absent
Zika Virus ZIKV	*Aedes* spp.; also of lesser importance are certain other genera	South America; spread sporadically in many countries (incl. India) across the world	Some States only
Japanese encephalitis JEV	*Culex* spp. mainly mosquitoes belonging to *Culex vishnui* subgroup	Southeast Asia, Pacific.	Mainly in Uttar Pradesh, eastern and southern as well as NE States

HISTORICAL ACCOUNT OF TAXONOMY OF INDIAN MOSQUITOES

If for a moment proverbial references to mosquitoes in the Indian scriptures of yore are set aside simply because of their vernacular nature, and also the first ever mosquito (*Anopheles stephensi*) brought famously on record as "dappled wings" by Major Dr Ronald Ross on course to his epoch-making discovery of the inextricable 'malaria-mosquito' connection in 1897 is also overlooked for its lack of modern scientific nomenclature, then the very first authoritative catalogue of Indian mosquitoes was prepared by Dr F.V. Theobald in his five volume-list of world species in 1910.[8] Thereafter, several prominent taxonomic works were published in different reputed periodicals particularly *Indian Journal of Medical Research*, culminating into a synoptic account of taxonomic description for individual species (totally 288, including 43 Anophelinae) in the famous *The Fauna of British India* series.[9,10] The latter, in spite of lately becoming out-of-date in context with modern classification and identification, besides outright expulsion of Dixini and Chaoborini from Culicidae, and extensive instances of species' synonymization, still continue to be the most authentic reference works on the Indian mosquitoes. Post-independence as India waged a war against the devastating malaria some very useful field-guides about mosquito identification were produced.[11-13] However, all these monographs dealt with *Anopheles* mosquitoes, largely due to an unprecedented high importance tagged with malaria in the country in those days.[14]

Between 1950 and 1970 almost all medical entomologists worked for malaria eradication and nearly succeeded as well since less than one million cases were reported without a single death during mid-1960s.[15] This kind of focus on anti-malaria campaign, however, overshadowed any appreciable attention to other (non-anopheline) mosquitoes notwithstanding rise in both intensity and distribution of diseases like *Cx. quinquefasciatus*-transmitted lymphatic filariasis and *Aedes aegypti*-mediated dengue.[16] Yet, a few fragmentary but significant publications were brought out on regional distribution of culicines in the Lower Himalayas, the Western and The Eastern Ghats, Andaman & Nicobar Islands, north-eastern states of seven sisters, the Thar Desert, the Great Rann of Kutch, and Malwa region of Punjab.[17-26] A comprehensive check-list however was for the first time published by the author of this publication,[27] which was updated from time-to-time by many authors.[4,28,29] Some authors have emphasized on ecosystem-based mosquito sampling, e.g., xeric, sylvatic and mangrove.[30, 31,32]

REFERENCE MUSEUMS FOR INDIAN MOSQUITO SPECIES

The oldest museums or depositories of type specimens is the Indian Museum, Kolkata much of which is now in disarray but at one time even Dr F.V. Theobald had to come down from England to this important repository for preparing his *magnum opus* of the world checklist of mosquitoes.[5] Another dedicated mosquito museum of various type specimens is the present day's National Centres for Diseases Control (erstwhile National Institute of Malaria; later National Institute of Communicable Diseases), Delhi where unfortunately the mosquitoes are currently in a rather dilapidated state of affairs. During past almost 50-60 years several institutes and centres under the country's premier scientific organization, the Indian Council of Medical Research, have evolved into a stronghold of medico-entomological investigations particularly in context with mosquito-transmitted diseases (e.g., Centre for Research in Medical Entomology, Madurai, Vector Control Research Centre, Puducherry, National Institute of Malaria Research, Delhi, Regional Medical Research Centre, Dibrugarh, and National Institute of Virology, Pune) which have established exquisite research museums housing type specimens (i.e., holotypes, allotypes, paratypes etc.) of various different new species described in recent past.[33-39] Some of these institutions have also produced detailed reports on deposits in the museums for guidance. [35,38, 39]

SIBLING SPECIES COMPLEXES

There are as many as six *Anopheles* species in India which are complexes of sibling species, while several others in Culicinae need urgent attention in this context (Table 3).[40] These complexes carry immense epidemiological significance since some of these are vectors which only need to be targeted for controlling. Some of these are annotated below.

1. *Anopheles culicifacies* Giles

Anopheles culicifacies, which also has it's cradle in India*,* is the most important vector responsible for more than 65% of malaria cases in the country particularly in the rural environment, although it is absent in the islands of Lakshadweep and Andaman & Nicobar.[15] The species complex comprises five sibling species, namely A, B, C, D and E; among all siblings, Species A and E are

the most important vectors while Species B is a non-vector. These five sibling species overlap each other in distribution in different proportions and a clear understanding of whether a vector or two among them is predominantly prevalent is to be inevitably determined to understand the intensity of malaria transmission, on one hand, and to bring about effective vector control, on the other.

Table 3. Sibling species complex of *Anopheles* mosquitoes in India

Species	Sibling Species Complex	Designated Species
Anopheles culicifacies	5	A, B, C, D and E
Anopheles fluviatilis	4	S, T, U and V
Anopheles subpictus	4	A, B, C and D
Anopheles annularis	2	A and B
Anopheles dirus	7 (In India only 2 species D & E occur)	*An. dirus* s.s. (species A), *An. cracens* (species B), *An. scanloni* (species C), *An. baimaii* (species D), *An. elegans* (species E), *An. nemophilous* (species F), *An. takasagoensis,* and a cryptic species tentatively designated as *An.* aff. *takasagoensis.*
An. sundaicus	4	*An. sundaicus* s.s., *An. epiroticus* (formerly species A), *An. sundaicus* species D and *An. sundaicus* species E.

2. *Anopheles dirus* species complex

There are eight sibling species in the complex - all forest dwellers and serious vectors of malaria, seven of which have been formally named, i.e., *An. dirus* s.s. (species A), *An. cracens* (species B), *An. scanloni* (species C), *An. baimaii* (species D), *An. elegans* (species E), *An. nemophilous* (species F), *An. takasagoensis*, and a cryptic species tentatively designated as *An*. aff. *takasagoensis*. Among these member species, only *An. baimaii* and *An. elegans* are prevalent in India with distinct distribution range and epidemiological significance. *Anopheles baimaii* is widely abundant in the northeast States where it pre-eminently transmits malaria.

3. *Anopheles fluviatilis* species complex

A dangerous vector for malaria contributing approximately 12-15% of all the annually reported cases, *Anopheles fluviatilis* s.l. is widespread in the mountainous

regions and foothill areas. The species complex comprises four sibling species, i.e., S, T, U and V, based on cytotaxonomic investigations on polytene chromosomes.

4. Anopheles sundaicus species complex

Besides a small focus in the Kutch area of Gujarat, this species is a major vector in Andaman & Nicobar Islands, besides many other island nations in the Southeast Asia. *Anopheles sundaicus* species complex s.l. is a complex of four species, i.e., *An. sundaicus* s.s., *An. epiroticus* Linton & Harbach (formerly species A), *An. sundaicus* species D and *An. sundaicus* species E. In Andaman and Nicobar islands, it breeds in brackish water, the populations of which have been characterized to be cytotype species D. It is largely a brackish water species breeding in a variety of habitats such as swamps, lagoons, creeks etc.

UNRESOLVED TAXONOMIC SITUATION OF VARIANTS OR SUBSPECIES WITHIN *ANOPHELES STEPHENSI* LISTON

Anopheles stephensi Liston is a major urban vector for malaria in India, transmitting more than 10% (next only to *An. culicifacies* and *An. fluviatilis*) of all cases annually. It is also a primary vector in The Thar Desert region in northwestern Rajasthan State. The species is regarded to possess three subspecies or variants, viz., *An. stephensi* Type Species, Intermediate and *An. stephensi* var. *mysorensis*, based on counts of egg ridges and spiracular length. *Anopheles stephensi* in the Thar Desert has been advocated to be a different species.[41] It is noteworthy to mention here that recently the species has extended its distribution to the east Africa, and already a few countries have documented *An. stephensi*-induced malaria in those countries.

INVASIVE ALIEN SPECIES (IAS) IN INDIA POST-'FAUNA OF BRITISH INDIA' (FBI) VOLUMES

Very little work has been done in India in this context, albeit a few stray instances. Before *Anopheles dirus* s.l. (*sensu lato*, i.e., *An. dirus* complex) was discovered and sibling species were properly named, the closest species recognized in India was *An. balabacensis.* Subsequently, *An. baimaii* was also reported from

many parts of the country, mainly from the north-eastern states of Assam region. Invariably all of the *An. dirus* species complex mosquitoes are vectors of malaria in Asian forested zones.[42] Of the three species prevalent in India, at least *An. dirus* Peyton & Harrison, 1979, and *An. baimaii* Sallum & Peyton, 2005, are clearly the invasive alien species to India in recent times. Some species were brought on record of the Indian fauna for the first time, such as, *Culex (Lophoceraomyia) pilifemoralis, Culex (Lophoceraomyia) wilfredi, Heizmannia (Heizmannia) chengi*, *Aedes fumidus* and *Aedes amesii* and it needs to be explored if these species are to be regarded invasive alien species.[32]

NEW SPECIES DESCRIPTIONS FOLLOWING 'THE FAUNA OF BRITISH INDIA' VOLUMES

By the dates, the two *magnum opuses* by Christophers (1933) and Barraud (1934) had appeared in the *Fauna of British India* series a total number of 336 species were inventoried. During the subsequent decades spawning nine decades only 75 species were described *de novo*. It is noteworthy that compared to a nearly dozen entomologists in the erstwhile Malaria Institute of India, presently well over 500 entomologists in both government, non-government, universities and medical colleges are engaged in some kind of mosquito-related research but still number of new species being described is abysmally low.

SPECIES THAT ARE '*NOMEN NUDUM*'

At least two examples are readily available of such taxa which are now regarded as *nomen nudum* for the want of mandatory taxonomic documentation in support of the new species:

(1) *Anopheles krishnai* Sathe & Jagtap (2012). The purported new species under the Neocellia Series, described vaguely merely on the basis of morphological features without aid from the molecular criteria, does not provide credible evidence to support the recognition of a new species, largely due to the fact that the authors failed to cite the extensive work on the Series already done. In contrast to attempting to compare with the closely related taxa, their comparison with the rather distant group species only goes to show that authors

have no knowledge about the established procedure of describing a new species. For these reasons, and the bare fact that the authors have failed to indicate the place and date of their designated holotype in accordance with the norms set by International Code of Zoological Nomenclature, the species *An. krishnai* is hereby regarded as a *nomen nudum*.

(2) *Lutzia agranensis* Singh & Prakash, 2008.[43] This species, a *nomen nudum* in all probabilities, was described from larvae collected in Agra, Uttar Pradesh. The description was based on the 4th instar larvae collected from cement tank breeding with those of *Culex quinquefasciatus*, *Anopheles stephensi* and *Aedes aegypti* and the genitalia of male adults subsequently reared. However, authors have failed completely to offer any credible evidence to support recognition of their purported new species. They did not assign any holotype and lectotype and overlooked any morphological and molecular works. They had often believed their species to be very close to *Lutzia halifaxii* with which a brief, rather inconclusive, comparison was offered. This comparison does not support the recognition of a new species as suggested. Needless to re-emphasize that, in the line of acceptable norms in describing a new species, all the larva, pupa and adult should have been described, together with the molecular data, and contrasted with closely related species to ensure the validity of a new species. The authors have not only denied this inevitability, they have also failed to fulfil the criteria of availability for species names as per the *International Code of Zoological Nomenclature.* For these reasons it is nearly impossible to validate their species and, therefore, their proposed new species *agranensis* is here considered but a *nomen nudum.*

MAJOR TAXONOMIC TREATMENTS

As far as Indian fauna of mosquitoes is concerned, by far the most dependable works are those by Christophers (1933) and Barraud (1934), appreciably complemented by Puri (1960) Rao (1988) and Nagpal & Sharma (1995). On anopheline vectors' identification useful works are published by Wattal & Kalra (1961) and Das *et al*. (1990). Reuben *et al*. (1994) dealt with alacrity the various species under *Culex vishnui* subgroup, well-known for their role in the transmission of Japanese encephalitis. Very recently, Tyagi *et al*. (2012, 2014) and Tyagi (2020) have for the first time described in one single volume the taxonomy and

identification keys of all the Indian mosquito vectors belonging to subfamilies Anophelinae and Culicinae. [Note: All the above references have been numerally cited under REFERENCES, at the end].

SOME INTERESTING TAXONOMIC ANECDOTES

1. *Anopheles (Anopheles) pinjaurensis* Barraud, 1932: Known from the type locality only in Pinjaur near Kalka, Punjab, this species was described on the basis of single adult male.
2. *Anopheles (Cellia) culicifacies* Giles, 1901: Currently a sibling species complex of five species (A-E); only some of these are vectors. However, not a single alphabetically known taxon has been named in accordance with the International Council of Zoological Nomenclature.
3. *Anopheles (Cellia) subpictus* Grassi, 1899: In southern India this species' role in the transmission of Japanese encephalitis has been recently documented.[44]
4. *Stegomyia (Stegomyia) aegypti* (Linnaeus, 1762): In conventional literature it is allowed to say *Aedes aegypti*. It also transmits Zika virus in India.
5. *Stegomyia albopicta* (Skuse, 1895): In the literature in vogue it is still allowed to use the name *Aedes albopictus*. It is a major vector for chikungunya and second only to *Ae. aegypti* in transmitting dengue worldwide. In Kerala State, India, *Ae. albopictus* is the main vector for both dengue and chikungunya. The species originated in Calcutta, India but described by Skuse in Australia where the female type is also deposited.
6. *Toxorhynchites (Toxorhynchites) tyagii* Krishnamoorthy *et al*., 2013: This, along with *Tx. darjeelingensis* Tyagi *et al*. (2015), is so far the only species described after Independence, and also in honour of an Indian scientist, under the genus.
7. *Tewarius* Reinert, 2006 is the only Genus in the whole of Culicidae ever dedicated to an Indian Culicidologist, Mr S.C. Tewari. Three species are so far described under this genus.[29]

ADDITIONAL INFORMATION WITH ANNOTATIONS ON TAXA OF INDIAN MOSQUITOES DESCRIBED AFTER TYAGI (2020)[29]

1. *Uranotaenia* (*Pseudoficalbia*) *pseudostricklandi* Natarajan, Rajavel & Jambulingam, 2018
2. *Paraedes jambulingami* Natarajan *et al.* 2019
3. *Heizmannia* (*Heizmannia*) *rajagopalani* Natarajan *et al*. 2020
4. *Anopheles* (*Cellia*) *krishnai* Sathe & Jagtap (2012): This species has been adversely remarked in scientific debates, and on the basis of evidences available it is found disagreeable to be regarded as a 'good' new species. Accordingly, the proposed species has been consigned to '*nomen nudum*'.

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