

## SCIENTIFIC NOTE

### A TAXONOMIC CHECKLIST AND RELATIVE ABUNDANCE OF THE MOSQUITOES OF NEW YORK CITY

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**ABSTRACT.** This is the 1st time that a comprehensive checklist of the mosquitoes of New York City has been compiled. This list is based on an arrayed collection of 2.3 million mosquitoes trapped and identified from 1,369 locations in the city between 2000 and 2017. Forty-seven species and 6 subspecies were identified belonging to 9 mosquito genera. *Culex pipiens* was the most prevalent species, most frequently encountered throughout the city. Over time, species diversity in the genus *Aedes* has increased from 10 species in the 1930s to 23 species in the recent surveys (2000–17). Invasive species *Aedes albopictus* and *Ae. japonicus japonicus*, which were rare in 2000, are now well established in all 5 boroughs of the city.

**KEY WORDS** Checklist, Culicidae, distribution, mosquitoes, New York City

Mosquitoes are significant to people both as nuisance and as vectors of human diseases. The superfluity of mosquitoes endangers the standard of living and abets the transmission of pathogens that cause malaria, viral encephalitides, filariasis, and other diseases. Recently, climate change, globalization, and increased international travel have opened up new territories for mosquito species and mosquito-borne illnesses outside their native/endemic regions (Weaver 2013, Leta et al. 2018). Invasive species such as *Aedes albopictus* (Skuse) and *Ae. japonicus* (Theobald) have occupied new lands where ecological conditions are suitable for colonization (Bartlett-Healy 2012). Over the past 2 decades, emerging arboviruses such as West Nile, dengue, chikungunya, and Zika virus caused significant outbreaks in many countries in the western hemisphere where potential vectors of these viruses were present (Hennessey et al. 2015, Weaver and Lecuit 2015, Fauci and Morens 2016). For instance, West Nile virus (WNV) first entered the Western hemisphere in 1999 in New York City (NYC, the city) and then rapidly spread throughout North America and many countries in South America (Kilpatrick 2011). Since its introduction in the USA, WNV has caused several localized and regional epidemics in the past 19 years (Vanichanan et al. 2016). The introduction and rapid geographic expansion of WNV in the Americas alerted public health professionals to the need to maintain awareness of other potential mosquito-borne infections abroad (Leta et al. 2018). With the high volume of international travel, NYC has had larger numbers of imported dengue, chikungunya, and Zika virus cases compared to other locales in the USA, when these viruses emerged in South and Central America and the Caribbean. Several hundred travel-related human

cases of these viruses are identified annually in the city (Bajwa et al. 2016). The city has diverse mosquito fauna including potential vectors of many exotic diseases. In the light of aforementioned entomologic/epidemiologic information, monitoring the historical and spatial distribution of mosquitoes is an important element in the risk assessment of both existing and emerging mosquito-borne diseases (Ibanez-Justicia et al. 2015).

Several accounts of the mosquitoes of New York State have been published in books and journals (Felt 1904; Howard et al. 1912–1917; Richard 1938; Matheson 1944; Barnes et al. 1950; Means 1979, 1987), but with limited or incomplete reference to the fauna of NYC. An entomologic survey of NYC conducted in 1935–36 documented the presence of 26 mosquito species (Fellton 1936). However, there has been no published taxonomic checklist of the mosquitoes of NYC. This paper provides the 1st comprehensive list of mosquitoes found in the city along with relative abundance and spatial distribution of the key mosquito species of NYC.

With approximately 8.5 million people, NYC is the largest city in the USA (US Census Bureau 2016). The city consists of 5 counties/boroughs, including compactly populated Manhattan; densely populated Bronx, Brooklyn, and Queens; and fairly suburban Staten Island. The city has a wide range of mosquito habitats, including countless discarded containers in residential areas, >150,000 storm drains, hundreds of thousands of larval habitats in >28,000 acres of parkland, 5,000 acres of cemeteries, and 15,000 acres of undeveloped freshwater and tidal wetlands with low and high marshes, and upland areas (Bajwa et al. 2016). From 2000 to 2017, the NYC Health Department collected and identified 2.3 million adult mosquitoes across the city from 1,369

locations (4.5 trap-sites/mi<sup>2</sup>). A variety of different mosquito sampling devices and strategies were used to increase the probability of collecting rare and new-record specimens for NYC. Each survey site had a CO<sub>2</sub>-baited Centers for Disease Control and Prevention light trap (John W. Hock Company, Gainesville, FL) and Reiter's gravid trap (John W. Hock Company; with 1-wk-old rabbit-food infusion) for a total of 61,539 trap-days from 2000 to 2017. BG Lure<sup>®</sup>-baited Biogents Sentinel traps (Biogents AG, Regensburg, Germany) were deployed for a total of 3,239 trap-days in 2016 and 2017. In addition, several hundred larval mosquitoes were collected, reared to adult stage, and identified to species. All collected specimens were identified morphologically using taxonomic keys by Darsie and Ward (2005) and Schultz (2009).

Analysis of our 18-year mosquito collection indicates 47 mosquito species in 9 genera in NYC. Light traps collected 1,360,507 mosquitoes belonging to 47 species. Gravid traps collected 660,918 mosquitoes in 43 species. Twenty-one species were collected in Biogents Sentinel traps and 25 species by rearing field-collected mosquito larvae. Mosquito genera from all 5 boroughs of the city include (number of species in parentheses): *Aedes* (23), *Anopheles* (7), *Coquillettidia* (1), *Culex* (5), *Culiseta* (4), *Orthopodomyia* (1), *Psorophora* (4), *Toxorhynchites* (1), and *Uranotaenia* (1). Over time, diversity has increased in the genus *Aedes*—from 10 species in the 1930s (Fellton 1936) to 23 species in the recent surveys (2000–17).

The checklist includes rarely encountered and sporadic species as well as those more abundant and widespread. Field specimens of all listed species were found in multiple seasons, ranging from 3 to 18 years. Among the collection, 6 subspecies were identified, including *Culex pipiens pipiens* Linnaeus, *Cx. pipiens molestus* Linnaeus (Bajwa and Zuzworsky 2016), *Ae. vexans vexans* (Meigen), *Ae. vexans niponii* (Meigen), *Ae. japonicus japonicus* (Theobald), and *Toxorhynchites rutilus septentrionalis* (Dyar and Knab). Not all species in the checklist have previously been reported in NYC. In the list, new records are marked with an asterisk. During 2000, 2 invasive species, *Ae. japonicus japonicus* and *Ae. albopictus*, were recognized for the 1st time in NYC (Miller 2001). During the past 18 years (2000–17), a few specimens of *Ae. punctor* (Kirby), *Ae. spencerii spencerii* (Theobald), *Ae. mitchellae* (Dyar), and *Tx. splendens* (Wiedemann) were also identified. Due to their rare occurrence, these species are considered accidental species and are not included in the checklist. From 1794 to 1805, NYC was plagued by multiple outbreaks of yellow fever (Heaton 1946, HM 2000). The epidemic was precipitated by *Ae. aegypti* (Linnaeus), a mosquito species that is incapable of overwintering in NYC (Bajwa et al. 2016) and other temperate climates (Weaver 2013), but was reintroduced every summer by trade ships (Bajwa et al. 2016). In the past 18

years, we did not collect a single specimen of *Ae. aegypti* in NYC.

With a relative abundance of 22.7%, *Cx. pipiens* was the most prevalent and most frequently encountered mosquito species throughout the city (Fig. 1). Other common species (relative abundance in parentheses) such as *Cx. salinarius* Coquillett (18.1%), *Ae. sollicitans* (Walker) (9.3%), *Ae. taeniorhynchus* (Wiedemann) (6.58%), *Coquillettidia perturbans* (Walker) (4.6%), *Ae. cantator* (Coquillett) (1.76%), and *Ae. trivittatus* (Coquillett) (1.1%) were trapped in large catches (per trap-day) from certain habitats/localities or during specific times in the mosquito season (April–October). Species such as *Ae. vexans vexans* (10.1%), *Cx. restuans* Theobald (6.1%), and *Ae. albopictus* (5.03%) had a citywide presence. Relatively less common species were *Ae. triseriatus* (Say) (0.79%), *Psorophora ferox* (von Humboldt) (0.45%), *Anopheles quadrimaculatus* Say (0.29%), *Cx. erraticus* (Dyar and Knab) (0.27%), *An. punctipennis* (Say) (0.17%), *Ae. japonicus japonicus* (0.13%), *Ae. canadensis* (Theobald) (0.13%), *Cx. territans* Walker (0.04%), *Ps. confinnis* (Lynch Arribáizaga) (0.04%), and *Ae. cinereus* Meigen (0.03%). All the abovementioned species were trapped every season in the past 18 years. Geographical distribution of some important mosquito species is depicted in Fig. 1. Inverse Distance Weighting Interpolation (Allen and Shellito 2008) was used to develop the distribution maps.

## Checklist of the Mosquitoes of New York City

### Genus *Aedes* Meigen

#### Subgenus *Aedes* Meigen

##### 1. *Aedes cinereus* Meigen

#### Subgenus *Aedimorphus* Theobald

##### 2. *Aedes vexans* (Meigen) (subspecies *vexans* and *niponii*)

#### Subgenus *Finlaya* Theobald

##### 3. *Ae. japonicus japonicus* (Theobald)\*

#### Subgenus *Ochlerotatus* Lynch Arribáizaga

##### 4. *Ae. atropalpus* (Coquillett)\*

##### 5. *Ae. aurifer* (Coquillett)

##### 6. *Ae. canadensis canadensis* (Theobald)

##### 7. *Ae. cantator* (Coquillett)

##### 8. *Ae. euedes* Howard, Dyar, and Knab\*

##### 9. *Ae. excrucians* (Walker)\*

##### 10. *Ae. fitchii* (Felt and Young)

##### 11. *Ae. flavescens* (Müller)\*

##### 12. *Ae. grossbecki* Dyar and Knab\*

##### 13. *Ae. implicatus* Vockeroth\*

##### 14. *Ae. intrudens* Dyar\*

##### 15. *Ae. sollicitans* (Walker)

##### 16. *Ae. riparius* Dyar and Knab\*

##### 17. *Ae. sticticus* (Meigen)\*

##### 18. *Ae. stimulans* (Walker)

##### 29. *Ae. taeniorhynchus* (Wiedemann)

##### 20. *Ae. trivittatus* (Coquillett)

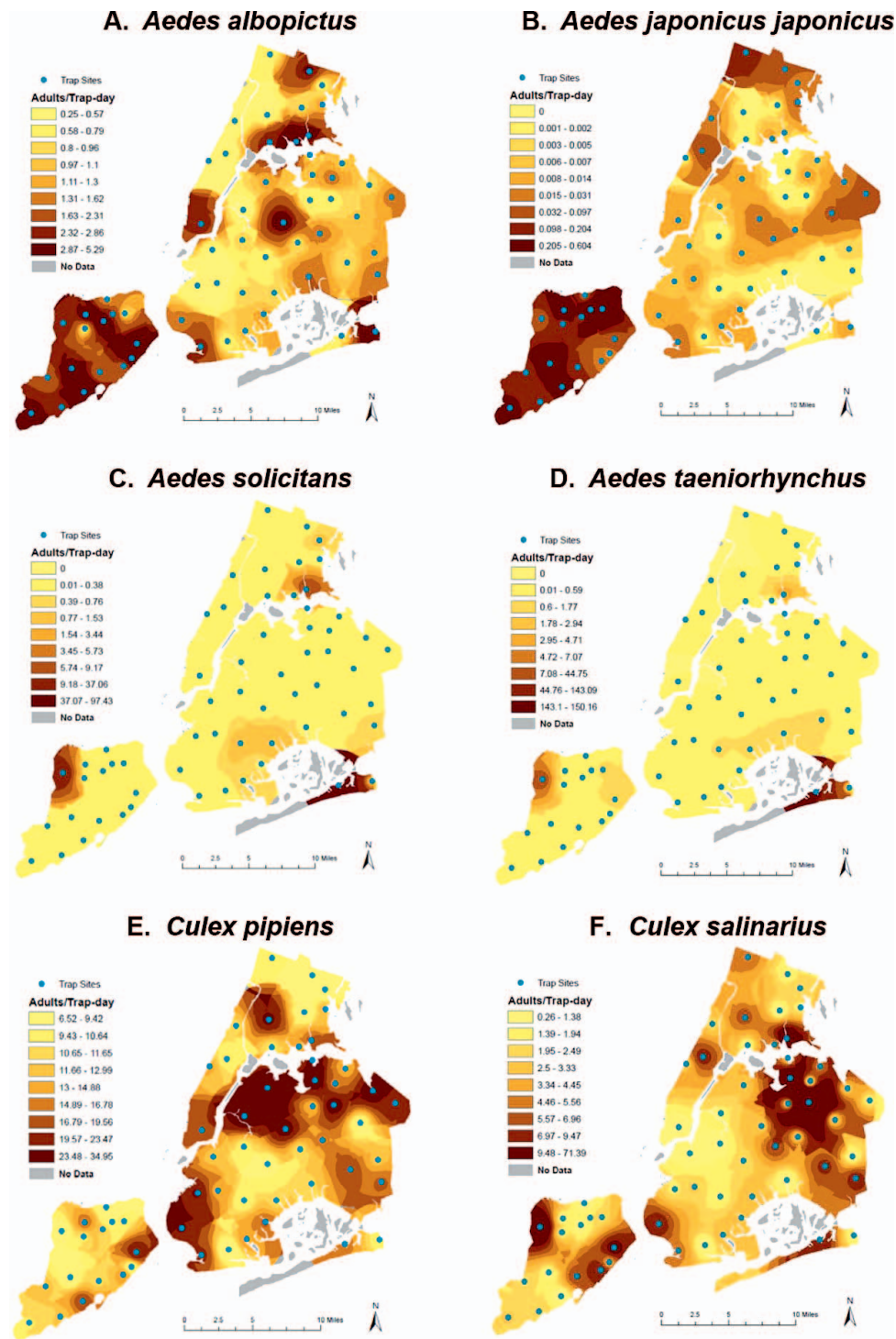


Fig. 1. Geographical distribution of a few common mosquito species of New York City.

Subgenus *Protomacleaya* Theobald

- 21. *Ae. hendersoni* Cockerell\*
- 22. *Ae. triseriatus* (Say)

Subgenus *Stegomyia* Theobald

- 23. *Ae. albopictus* (Skuse)\*

**Genus *Anopheles* Meigen**Subgenus *Anopheles* Meigen

- 24. *Anopheles barberi* Coquillett\*
- 25. *An. bradleyi* King\*
- 26. *An. crucians* Wiedemann
- 27. *An. earlei* Vargas\*
- 28. *An. punctipennis* (Say)
- 29. *An. quadrimaculatus* Say
- 30. *An. walkeri* Theobald\*

**Genus *Coquillettidia* Dyar**Subgenus *Coquillettidia* Dyar

- 31. *Coquillettidia perturbans* (Walker)

**Genus *Culex* Linnaeus**Subgenus *Culex* Linnaeus

- 32. *Culex pipiens* Linnaeus (form *pipiens* and form *molestus*)
- 33. *Cx. restuans* Theobald
- 34. *Cx. salinarius* Coquillett

Subgenus *Melanoconion* Theobald

- 35. *Cx. erraticus* (Dyar and Knab)\*

Subgenus *Neoculex* Dyar

- 36. *Cx. territans* Walker

**Genus *Culiseta* Felt**Subgenus *Climacura* Howard, Dyar, and Knab

- 37. *Culiseta melanura* (Coquillett)

Subgenus *Culicella* Felt

- 38. *Cs. morsitans* (Theobald)\*
- 39. *Cs. inornata* (Williston)
- 40. *Cs. impatiens* (Walker)\*

**Genus *Orthopodomyia* Theobald**Subgenus *Orthopodomyia* Theobald

- 41. *Orthopodomyia signifera* (Coquillett)

**Genus *Psorophora* Robineau-Desvoidy**Subgenus *Janthinosoma* Lynch Arribálzaga

- 42. *Psorophora ferox* (von Humboldt)\*

Subgenus *Psorophora* Robineau-Desvoidy

- 43. *Ps. ciliata* (Fabricius)
- 44. *Ps. confinnis* (Lynch Arribálzaga)
- 45. *Ps. howardii* Coquillett\*

**Genus *Toxorhynchites* Theobald**Subgenus *Lynchiella* Lahille

- 46. *Toxorhynchites rutilus septentrionalis* (Dyar and Knab)\*

**Genus *Uranotaenia* Lynch Arribálzaga**Subgenus *Uranotaenia* Lynch Arribálzaga

- 47. *Uranotaenia sapphirina* (Osten Sacken)

\* Species/subspecies not found in 1936 survey (Fellton 1936).

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