The geographic distribution of mosquito species in Sweden

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Abstract: Surveillance of the actual distribution of mosquito species in Northern Europe is fundamental for evaluating risk for emerging pathogens, and for research on potential vectors. The Swedish mosquito fauna composition and geographic distribution, originally described by Professor Christine Dahl in the 1970´s, included 43 species. We have compiled the information published from 1978 to 2012, and our own surveillance data from 2001 to 2013, and compared this with the species list and geographic distribution provided in "*Taxonomy and geographic distribution of Swedish Culicidae*" by Dahl (1977). New species detected during these 36 years were *Culiseta (Culicella) ochroptera* (Peus, 1935) published 1984, *Aedes (Aedes) rossicus* Dolbeskin, Goritzkaja & Mitrofanova, 1930 published 1986, *Anopheles (Anopheles) beklemishevi* published 1986, *Aedes (Ochlerotatus) euedes* (Howard, Dyar & Knab, 1912) published 2001, *Aedes (Ochlerotatus) nigrinus* (Eckstein, 1918) first recorded in 2012, and *Anopheles (Anopheles) algeriensis* Theobald, 1903, first recorded in 2013. We provide maps with the distribution by province for each species, including historic information up until 1977, and new records from 1978 to 2013, showing the similarities and differences between the old and the new records. Important findings in recent years include the wide distribution of the Sindbis virus enzootic vector *Culex (Culex) torrentium* Martinii, 1925, and the more limited distribution of the potential West Nile virus vector *Culex (Culex) pipiens* Linnaeus, 1758. The updated list of mosquito species in Sweden now includes 49 species. ***Journal of the European Mosquito Control Association* 31: 21-35, 2013**

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Introduction

Worldwide, mosquitoes (Diptera: Culicidae) are vectors for a large variety of pathogens. The blood-feeding females transmit the protozoa causing malaria, the filarial worms causing elephantiasis, and the viruses causing dengue fever, yellow fever, Rift Valley fever, West Nile fever, and many additional viruses causing encephalitis and polyarthritis (Mullen & Durden, 2000). In addition to their major importance as vectors of human pathogens, mosquito females can attack humans and other mammals in very large numbers causing nuisance of a magnitude that negatively affects individuals and society, and may have large economic consequences. In recent decades, it is evident also that Swedish mosquitoes are infected with human pathogenic viruses such as Sindbis virus (for reviews see Lundström, 1994, 1999), and the bacteria causing Tularemia in humans and other mammals (Lundström *et al*., 2011). In addition, the flood-water mosquito *Aedes (Ochlerotatus) sticticus* (Meigen, 1838) is superabundant and causes massive nuisance problems in some areas (Schäfer *et al*., 2008, Schäfer & Lundström, 2009). These recent findings show that in Sweden, as in many other European countries, some mosquito species are causing significant health problems that are a burden for individuals and society. Information on mosquito species and their respective geographic distribution is fundamental for the goal of reducing the impact of emerging vector-borne viral zoonoses in Europe (Ahmed *et al*., 2009).

The composition of the Swedish mosquito fauna and their geographic distribution was described by Professor Christine Dahl based on previously published records, examination of specimens from collections in museums, and many years of sampling for mosquito larvae in major parts of Sweden (Dahl, 1977). In total, the mosquito fauna was suggested to include 43 species (Dahl, 1977). Several additional species were reported in the following decades (Jaenson *et al*., 1984, Jaenson, 1986, Jaenson *et al*., 1986a, Blackmore & Dahl, 2001). In addition, several studies were published providing new information on the geographic occurrence of mosquito species in Sweden. A few studies were focused on the geographic occurrence of individual species or species groups including the *Anopheles (Anopheles) maculipennis* Meigen, 1818 complex (Jaenson *et al*., 1986a), *Aedes (Finlaya) geniculatus* Olivier, 1791 (Dahl & Blackmore, 2001), *Ae. sticticus* (Schäfer & Lundström, 2009), and the sympatric sibling species *Culex (Culex) pipiens* Linnaeus,

1758 and *Culex (Culex) torrentium* Martini, 1925 (Hesson *et al*., 2011).

The enormous nuisance caused by the superabundant flood-water mosquito *Ae. sticticus* in the River Dalälven floodplains in the summer of 2000 (Schäfer *et al*., 2008), induced a need for data on mosquito species and abundances. Therefore, a long-term surveillance programme for mosquitoes in the River Dalälven floodplains was established in 2001. This surveillance programme has been active for 13 years, and similar but smaller surveillance programmes have been established for one to four years in other parts of Sweden. Now, several decades after the "*Taxonomy and geographic distribution of Swedish Culicidae*" by Dahl (1977), and with the addition of several new species, and a massive amount of recent data on the mosquito fauna, there is a need for a new comprehensive compilation of the geographic distribution of mosquito species in Sweden.

The aim of the present paper is to provide a common platform for further studies of the Swedish mosquito fauna by summarising the last 36 years of provincial records for mosquito species, and comparing these records to the information provided by Dahl (1977). A further aim is to continue the work initiated by Schäfer *et al*. (2004) on defining the Mosquito Functional Group (MFG) for all mosquito species recorded for Sweden. A total of 10 MFG are defined based on four biological characteristics (oviposition sites, overwintering life stage, preferred blood-meal hosts, number of generations per year) and provided a code (MFG 1a-1e, 2a-2e). In addition, MFG 2a (snow-pool mosquitoes) and MFG 2b (flood-water mosquitoes), have been provided with common names.

Materials and Methods

Historic material: Dahl (1977) is the starting point for our compilation of geographic distribution data on mosquito species in Sweden, and older references can be extracted from this important summary on historical data. We adopted the method of geographic presentation, based on the Swedish provinces (Figure 1a), to be able to build on the available information from Dahl (1977) on geographic distribution. However, Lappland was not divided into sub-province in the present study, because we were unable to find relevant geographic boundaries of the sub-provinces.

Published material: The published provincial records of mosquito species in Sweden, from the years 1978 to 2012, were mainly extracted from articles and books that were already in our possession. Internet based searches gave nothing new, while backtracking in reference list in the identified publications gave a few more articles.

Own sampling for mosquitoes: In the years 2001 to 2012, the authors sampled and identified a very large number of mosquitoes in the municipalities of the River Dalälven floodplains, and in several other municipalities in various parts of Sweden. In addition, smaller more focused sampling efforts have been conducted at some areas in eastern and southern Sweden.

The mosquito surveillance programme in the River Dalälven floodplains was established in May 2001 (http://www.mygg.se), and is based on a strategy with bi-weekly mosquito sampling (one night every odd week) starting in May (week 19) and ending in September (week 37) each year. The original surveillance programme includes approximately 35 trap sites in the floodplains, and for mosquito sampling, carbon dioxide baited Centres for Disease Control miniature light traps (CDC-traps) were used. The same bi-weekly trapping schedule was applied in additional surveillance programmes in several other municipalities in various parts of Sweden. Here we use data from the mosquito surveillance in the seven municipalities: Avesta [Dalarna province], Sala [Västmanland province], Heby and Tierp [Uppland province], Sandviken, Gävle and Älvkarleby [all Gästrikland province]) of the River Dalälven floodplains during 2001–2011, and with additional data by municipality from Östhammar [Uppland province] 2007–2009, Sunne [Värmland province] 2005–2008, Forshaga [Värmland province] 2010–2012, Örebro [Närke province] 2004, Skövde [Västergötland province] 2006–2009, Danderyd [Uppland province] 2008–2012, Umeå [Västerbotten province] 2009, Luleå [Norrbotten province] 2009, and Kristianstad [Skåne province] 2005–2009. Smaller sampling sessions were performed at the east coast of the province of Småland and the provinces of Skåne and Blekinge in 2007 and at the east coast of the provinces of Uppland and Gästrikland in 2009. Collected female mosquitoes were identified to species, or species complex, based on morphology and using the keys in Mohrig (1969), Gutsevich *et al*. (1974), Wood *et al*. (1979), and Becker *et al*. (2003, 2010). Usually all mosquitoes collected in a trap were identified, but because of the extremely large samples in some traps some nights (up to 77,000 mosquitoes per trap and night was recorded in the present study), it was decided to identify up to approximately 1,000 mosquitoes per trap and night.

Hesson *et al*. (2010, 2011) developed a molecular method for the secure identification of *Cx. pipiens* from *Cx. torrentium*, and used the method to investigate the distribution of these two species in Sweden. Some of the *Culex* mosquitoes used by Hesson *et al*. (2011) originated from the herein reported mosquito surveillance. In the results section, we report the morphologically identified *Cx. pipiens/torrentium* and the molecularly identified *Cx. pipiens* and *Cx. torrentium*, separated.

In 2012 and 2013, a mosquito surveillance based on privately run commercial counter-flow traps (the Mosquito Magnet counter-flow trap was dominated, but several other brands were also included) was established. The private owners were requested to empty their trap after 24 hrs of sampling, kill the mosquitoes by freezing, and send the frozen mosquito sample to the National Veterinary Institute, in Uppsala, for species analysis. The sampling strategy allows coverage of major parts of Sweden, and is planned for two complete years of sampling. The provided frozen mosquito samples were mostly in surprisingly good shape, and the specimens could be identified morphologically without major problems. Here we report on a fraction of the 2012 and the 2013 data that provide two new species for Sweden, the geographic distribution of records of these species, and a few other geographic species records.

It was decided to follow the traditional taxonomy for the family Culicidae, as specified in Knight & Stone (1977) and in the supplement by Ward (1984). The reason is the lack of consent between mosquito taxonomists about the change suggested by Reinert (2000). Thus, until there is evidence-based scientific agreement on a specific change in the mosquito taxonomic classification, the authors will stay with the traditional taxonomy. For the species *Culex (Neoculex) territans* Walker 1856, Ramos *et al*., (2003) suggested that the scientific name should be changed to *Culex (Neoculex) europaeus*

for the species occurring in Europe, based on morphological differences between the North American and the European specimens. However, the massive compilation on all mosquito species in Europe by Becker *et al.* (2010) continue using *Cx. territans* for the individuals occurring in European countries. The goal of the present study is not to solve this taxonomic dilemma, so the authors have decided to use *Cx. territans* for the Swedish specimens until there is evidence-based scientific agreement on the eventual change in scientific name for the species.

Results

Species recorded in the mosquito surveillance 2001-2013. The very large sampling effort using CDC-traps in the seven municipalities of the River Dalälven floodplains, and in several other municipalities and additional areas in Sweden, provided approximately 3,500,000 mosquitoes and 1,251,668 of these mosquitoes have been identified to species (Table 1). A total of 31 species, were recorded. A subsample of the individuals morphologically identified as *Cx. pipiens/torrentium*, were identified to species (*Cx. pipiens* or *Cx. torrentium*) as reported previously (Hesson *et al.*, 2011). However, the species morphologically identified as the *An. maculipennis* complex were not further identified to species in this study. The most common mosquito species in this collection was the superabundant flood-water mosquito *Ae. sticticus* (539,182 individuals identified, but real number several times higher), the snow-pool mosquito *Aedes (Ochlerotatus) communis* (De Geer, 1776) (200,229 individuals identified), and the flood-water mosquito *Aedes (Aedes) cinereus* Meigen, 1818 (165,349 individuals identified). The least common mosquito species were the frog-specialist *Culex (Neoculex) territans* Walker, 1856 (one individual identified), the snow-pool mosquito *Aedes (Ochlerotatus) flavescens* (Muller, 1764) (two individuals identified), the tree-hole specialist *Anopheles (Anopheles) plumbeus* Stephens, 1828 (two individuals identified), and *Aedes (Rusticoides) rusticus* (Rossi, 1790) (two individuals identified).

The 2012 nationwide surveillance based on 24 hrs capture with counter-flow traps provided the first record of *Aedes (Ochlerotatus) nigrinus* (Eckstein, 1918) for Sweden. A total of 16, three and one specimens were collected in the provinces of Norrbotten, Halland and Småland, respectively. In addition, one *Aedes (Rusticoides) refiki* (Medschid, 1928) was collected in the province of Öland, and several *Coquillettidia (Coquillettidia) richiardii* (Ficalbi, 1889) were collected in the province of Gotland. The 2013 nationwide surveillance provided the first record of *Anopheles (Anopheles) algeriensis* Theobald 1903 for Sweden. A total of 16 specimens were identified in two collections from the province of Gotland.

The diversity of mosquitoes, in the full season mosquito surveillance using CDC-traps, varied from the south to the north (Table 1). The province of Skåne had the highest mosquito diversity (24 species, 9 MFG), the provinces of Uppland, Västmanland, Värmland, Gästrikland and Dalarna had high mosquito diversity (20-24 species, 8 -9 MFG), the province of Närke had modest mosquito diversity (19 species, 7 MFG), and the provinces of Västerbotten and Norrbotten had low mosquito diversity (12-15 species, 6 MFG). A similar pattern was observed for the combined number of species and combined number of MFG from Dahl (1977) and the last 36 years of studies in Sweden (Figure 1b).

Mosquito species records published 1978-2012. The published geographic records of mosquitoes in this time period provided several species new to Sweden including *Culiseta (Culicella) ochroptera* (Peus, 1935) (Jaenson *et al.*, 1984), *Aedes (Aedes) rossicus* Dolbeskin, Goritzkaja & Mitrofanova, 1930 (Jaenson, 1986), and *Anopheles (Anopheles) beklemishevi* (Jaenson *et al.*, 1986a). Dahl (1997) added the species *Aedes (Ochlerotatus) behningi* Martini, 1926 and *Aedes (Ochlerotatus) euedes* (Howard, Dyar & Knab, 1912) without details on where the species were observed, but Blackmore & Dahl (2001) identified *Ae. euedes* in suction trap samples from the province of Gästrikland. Although mentioned by Dahl (1997), it has not been possible to find any reference to a specific geographic record of *Ae. behningi*, so this species is not included in this list of species recorded in Sweden (Table 2).

Jaenson *et al.* (1986a) made a contribution by the study on the distribution of species within the *An. maculipennis* complex in Sweden. Dahl & Blackmore (2001) described the occurrence of *Ae. geniculatus* in Sweden. Schäfer & Lundström (2009) provided detailed information on the geographic occurrence of the flood-water mosquito *Ae. sticticus* in Sweden, and also simulated the expected change in distribution that could occur as a consequence of climatic change. Hesson *et al.* (2011) sampled *Culex* larvae in 20 of the 25 provinces in Sweden, and identified the sympatric sibling species *Cx. pipiens* and *Cx. torrentium* to species to show the respective distribution and relative abundance of the species.

Andersson & Jaenson (1987) sampled mosquitoes for analysis of the preference of plants for nectar feeding, and provided species lists for areas in the province of Uppland, and in the province of Halland. Jaenson *et al.* (1986b) provided species lists for areas in the province of Hälsingland. Francy *et al.* (1989) sampled mosquitoes in search for mosquito-borne viruses, and provided species lists for areas in the provinces of Medelpad and Hälsingland. Schäfer & Lundström (2001) studied the mosquito fauna of forested swamps, and provided species lists for the provinces of Lappland and Skåne. Blackmore & Dahl (2001) compared the catch of mosquitoes and other insects in CDC-traps and in counter-flow traps, and provided species lists for the county of Gästrikland. Schäfer *et al.* (2004) studied the mosquito fauna of natural and constructed wetlands, and provided species lists for the provinces of Halland, Skåne, Östergötland, and Gästrikland. Schäfer *et al.* (2008) studied the mosquito fauna of the River Dalälven floodplains, and provided species list for the provinces of Gästrikland and Uppsala.

Historic and recent geographic distribution of mosquito species by province. The combined data from all studies on the Swedish mosquito fauna gives a comparatively good coverage of the country (Figure 1b). However, the presented number of species may not always show the actual number of species per province, since sampling effort was not equally distributed over the provinces, neither in the 1977 study nor in the last 36 years of mosquito surveillance in Sweden.

In the next section, we compile the distribution records for all the 43 species recognised by Dahl (1977) and the six more recently identified species, resulting in a total of 49 species presently recognised in Sweden. It has not been possible to find any published information on the veterinary importance of mosquito species occurring in Sweden. However, published information on medical importance is included when available.

Table 1. Mosquito species sampled by full season surveillance with CDC-traps in 12 provinces over the whole country in the years 2001 to 2012. The surveillance was performed during 11 full seasons in the provinces of Uppland, Västmanland, Gästrikland and Dalarna, seven seasons in the province of Värmland, four seasons in the province of Skåne, three seasons in the province of Västergötland, and one season in the provinces of Närke, Västerbotten and Norrbotten. For the provinces of Blekinge and Småland, only limited sampling was performed. The species are organised by their Mosquito Functional Group (MFG)[1], and include all 49 mosquito species recorded to date in Sweden.

MFG[1]	Species	Skån.[2]	Bleki.	Smål.	Västg.	Uppl.	Närk.	Västm.	Värml.	Gästr.	Dalar.	Västb.	Norrb.	Total
1a	*Cq. richiardii*	1008			396	19995	347	1966	1456	40393	1893	14	81	**67549**
1b	*An. algeriensis*													
1b	*An. claviger*	3501			246	1506	7	28	23	1120	119			**6550**
1c	*An. arthroparvus*													**0**
1c	*An. beklemishevi*													**0**
1c	*An. maculipennis sl*	10			49	674	12	250	99	1742	293	6		**3135**
1c	*An. maculipennis str*													**0**
1c	*An. messae*													**0**
1c	*Cs. alaskaensis*	2			12	132	1	15	4	212	38			**416**
1c	*Cs. annulanta*	170			43	138		9	5	27	1			**393**
1c	*Cs. bergrothi*	1				118	1	5	9	141	13	1	4	**293**
1c	*Cs. subochrea*													**0**
1d	*Cx. pipiens/torrentium*	5211	1		310	611	50	91	36	563	556	6	6	**7441**
1d	*Cx. pipiens*	72	3		32	26			8	9	7			**157**
1d	*Cx. torrentium*	6			1	14			8	10	3			**42**
1e	*Cx. territans*										1			**1**
2a	*Ae. annulipes*	179			11	1514	28	1451	322	695	281	12	13	**4506**
2a	*Ae. cantans*	3478	3	1	68	13078	165	2629	1624	10232	4253	71	154	**35756**
2a	*Ae. cataphylla*	109			1	247			6	55	5			**423**
2a	*Ae. communis*	1529	48	11	14	78323	140	1844	2554	93303	12500	5675	4288	**200229**
2a	*Ae. cyprius*													**0**
2a	*Ae. diantaeus*	2	6		2	8051	1	77	811	10849	6728	839	309	**27675**
2a	*Ae. euedes*													**0**
2a	*Ae. excrucians*								56					**56**
2a	*Ae. flavescens*						2							**2**
2a	*Ae. hexodontus*					9				1				**10**
2a	*Ae. impiger*													**0**
2a	*Ae. intrudens*			1	6	14075	129	16556	2641	8967	2783	193	36	**45387**
2a	*Ae. leucomelas*	55					13							**68**
2a	*Ae. nigripes*													**0**
2a	*Ae. pionips*													**0**
2a	*Ae. pullatus*													**0**
2a	*Ae. punctodes*													**0**
2a	*Ae. punctor*	278	1	1	11	8878	143	680	454	8109	1904	675	1811	**22945**
2a	*Ae. riparius*													**0**
2a	*Ae. refiki*[3]													**0**
2b	*Ae. caspius*	50				24				2				**76**
2b	*Ae. cinereus*	2847	197	70	1811	63561	1450	7798	19370	45419	21610	977	239	**165349**
2b	*Ae. detritus*	61												**61**
2b	*Ae. dorsalis*	4				2				3				**9**
2b	*Ae. geminus*													**0**
2b	*Ae. nigrinus*													**0**
2b	*Ae. rossicus*					28153		2257	710	29546	6197	6		**66869**
2b	*Ae. sticticus*	160	1	7	9172	177608	54	12484	76900	199364	63432			**539182**
2b	*Ae. vexans*	1509	4		1288	16891	29	809	17012	13788	3433	3		**54766**
2c	*Ae. geniculatus*	1				49		4	3	139	23			**219**
2c	*An. plumbeus*	2												**2**
2d	*Ae. rusticus*	2												**2**
2e	*Cs. fumipennis*													**0**
2e	*Cs. morsitans*	72	1		6	718	15	26	13	570	209	34	1	**1665**
2e	*Cs. ochroptera*	10			2	66	1	20	15	102	114	30	74	**434**

[1] The 10 Mosquito Functional Groups (MFG) are defined by Schäfer *et al.* (2004) based on four biological characteristics (oviposition sites, overwintering life stage, preferred blood-meal hosts, no of generations per year) and provided a code (MFG 1a-1e, 2a-2e). The number code 1 denotes that the species lay eggs on water surface, and 2 denotes that the species lay eggs on the soil. The letter codes (a-e) indicate the total classification based on overwintering life stage (egg, larvae, adult), preferred blood-meal hosts (mammal, bird, amphibian), and the number of generations per year (one or several). Two of the MFG´s have been provided with common names - MFG 2a (snow-pool mosquitoes) and MFG 2b (flood-water mosquitoes).

[2] Abbreviations for the provinces are Skån. = Skåne, Bleki. = Blekinge, Smål. = Småland, Västg. = Västergötland, Uppl. = Uppland, Närk. = Närke, Västm. = Västmanland, Värml. = Värmland, Gästr. = Gästrikland, Dalar. = Dalarna, Västb. = Västerbotten, Norrb: = Norrbotten.

[3] *Ae. refiki* mainly overwinter as eggs, rendering inclusion in MFG2a, but can also overwinter as larvae.

Table 2. The 49 mosquito species recorded in Sweden based on the combined information from Dahl (1977), additional publications 1978-2012[1], and by the authors' surveillance 2001-2013.

No	Genus	Subgenus	Species
1	*Anopheles*	*Anopheles*	*Anopheles algeriensis* Theobald, 1903
2			*Anopheles atroparvus* van Thiel, 1927
3			*Anopheles beklemishevi* Stegnii & Kabanova, 1976
4			*Anopheles claviger* (Meigen, 1804)
5			*Anopheles maculipennis* Meigen, 1818
6			*Anopheles messeae* Falleroni, 1926
7			*Anopheles plumbeus* Stephens, 1828
8	*Aedes*	*Aedes*	*Aedes cinereus* Meigen, 1818
9			*Aedes geminus* Peus, 1970
10			*Aedes rossicus* Dolbeskin, Goritzkaja & Mitrofanova, 1930
11	*Aedes*	*Aedimorphus*	*Aedes vexans* (Meigen, 1830)
12	*Aedes*	*Rusticoides*	*Aedes refiki* (Medschid, 1928)
13			*Aedes rusticus* (Rossi, 1790)
14	*Aedes*	*Finlaya*	*Aedes geniculatus* (Olivier, 1791)
15	*Aedes*	*Ochlerotatus*	*Aedes annulipes* (Meigen, 1830)
16			*Aedes cantans* (Meigen, 1818)
17			*Aedes caspius* (Pallas, 1771)
18			*Aedes cataphylla* (Dyar, 1916)
19			*Aedes communis* (De Geer, 1776)
20			*Aedes cyprius* (Ludlow, 1919)
21			*Aedes detritus* (Haliday, 1833)
22			*Aedes diantaeus* (Howard, Dyar & Knab, 1912)
23			*Aedes dorsalis* (Meigen, 1830)
24			*Aedes excrucians* (Walker, 1856)
25			*Aedes euedes* (Howard, Dyar & Knab, 1912)
26			*Aedes flavescens* (Muller, 1764)
27			*Aedes hexodontus* (Dyar, 1916)
28			*Aedes impiger* (Walker, 1848)
29			*Aedes intrudens* (Dyar, 1919)
30			*Aedes leucomelas* (Meigen, 1804)
31			*Aedes nigrinus (Eckstein, 1918)*
32			*Aedes nigripes* (Zetterstedt, 1838)
33			*Aedes pionips* (Dyar, 1919)
34			*Aedes pullatus* (Coquillett, 1904)
35			*Aedes punctodes* (Dyar, 1922)
36			*Aedes punctor* (Kirby, 1837)
37			*Aedes riparius* (Dyar & Knab, 1907)
38			*Aedes sticticus* (Meigen, 1838)
39	*Coquillettidia*	*Coquillettidia*	*Coquillettidia richiardii* (Ficalbi, 1889)
40	*Culex*	*Neoculex*	*Culex territans* Walker, 1856
41	*Culex*	*Culex*	*Culex pipiens* Linnaeus, 1758
42			*Culex torrentium* Martini, 1925
43	*Culiseta*	*Culiseta*	*Culiseta annulata* (Schrank, 1776)
44			*Culiseta alaskaensis* (Ludlow, 1906)
45			*Culiseta bergrothi* (Edwards, 1921)
46			*Culiseta subochrea* (Edwards, 1921)
47	*Culiseta*	*Culicella*	*Culiseta fumipennis* (Stephens, 1825)
48			*Culiseta morsitans* (Theobald, 1901)
49			*Culiseta ochroptera* (Peus, 1935)

[1] It has not been possible to find any reference to a geographic location where *Aedes (Ochlerotatus) behningi* Martini, 1926 has been recorded in Sweden. Therefore, although provided the sign "SF" by Dahl (1997), we cannot include the species in the table of species recorded in Sweden.

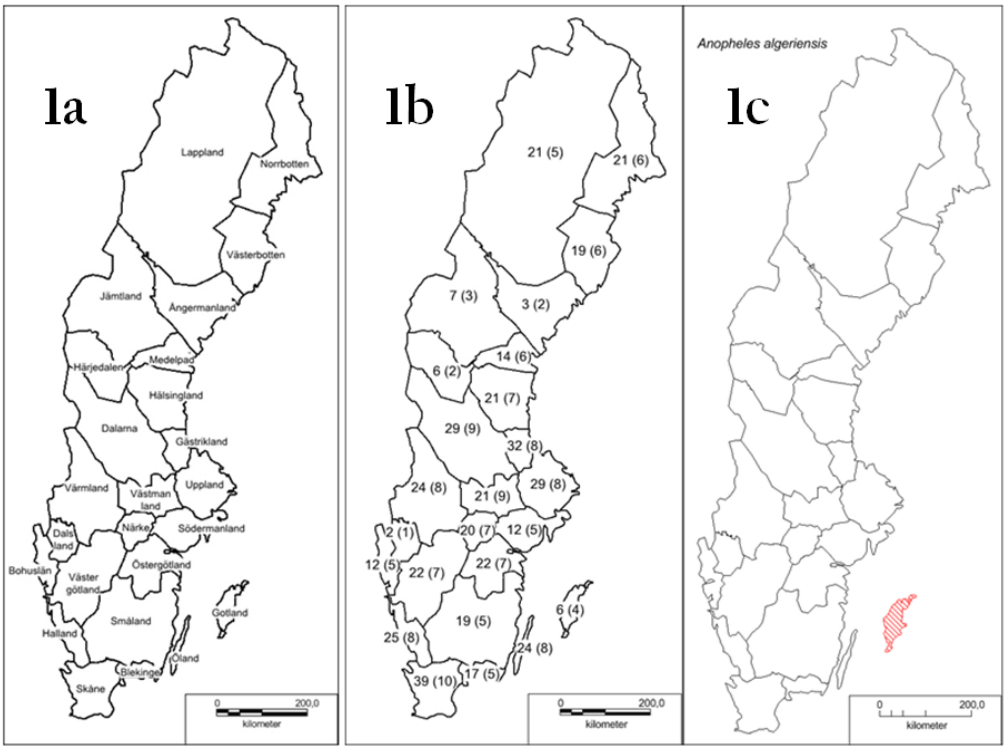

Figure 1. A map of Sweden with a) the geographic location of the 25 provinces, and b) the resulting number of species and Mosquito Functional groups based on combined records from Dahl (1977) and from the additional 36 years of mosquito sampling in Sweden, and c) the Swedish province distribution of *Anopheles (Anopheles) algeriensis*. **Legends**: ▨ species records from Dahl (1977), ▨ species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

For readers interested in the biology of the species, we suggest the excellent reviews by Becker *et al.* (2010).

Genus *Anopheles*

The genus *Anopheles* is represented by seven *Anopheles (Anopheles)* species in Sweden (Table 2).

***Anopheles (Anopheles) algeriensis* Theobald 1903** (Figure 1c). The species was first recorded in 2013 on the Island of Gotland, also province Gotland, on the Swedish south-east coast.

***Anopheles (Anopheles) atroparvus* van Thiel, 1927** (Figure 2a): The species was recorded in four provinces up to 1977, and in the 1980´s it was recorded in one further province (Jaenson *et al.*, 1986). The only recent records of *An. atroparvus* are from the province of Småland. Medical importance: Historically, malaria was a common disease in Sweden, and devastating epidemics of *Plasmodium vivax* malaria occurred in the 19th century, and *An. atroparvus* was probably the vector in coastal, brackish-water regions in southern Sweden (Jaenson *et al.* 1986a).

***Anopheles (Anopheles) beklemishevi* Stegnii & Kabanova, 1976** (Figure 2b): The species was not listed in 1977, and first recorded by Jaenson *et al.* (1986). The records of *An. beklemishevi* are from eight provinces in the central and northern parts of Sweden.

***Anopheles (Anopheles) claviger* (Meigen, 1804)** (Figure 2c): The published information up to 1977 showed the occurrence of *An. claviger* in five of the 25 provinces, from the south to the north. However, the more recent distribution records show occurrence in 10 provinces and only in southern Sweden.

***Anopheles (Anopheles) maculipennis* Meigen, 1818 *sensu latu*.** Species in the *An. maculipennis* complex are difficult to identify to species based on morphological characters, and the older published information therefore rarely separated the species. Jaenson *et al.* (1986a) defined the occurrence of *Anopheles (Anopheles) atroparvus* van Thiel, 1927, *Anopheles (Anopheles) beklemishevi* Stegnii & Kabanova, 1976, *Anopheles (Anopheles) maculipennis* Meigen, 1818 *sensu stricto*, and *Anopheles (Anopheles) messeae* Falleroni, 1926, from the *An. maculipennis* complex in Sweden.

Anopheles (Anopheles) maculipennis* Meigen, 1818 *sensu stricto (Figure 2d): The species was recorded from 12 provinces all over Sweden in 1977. The more recent distribution records are from seven provinces in southern Sweden, and it appears that in Sweden *An. maculipennis s. str.* is mainly southern in its distribution.

***Anopheles (Anopheles) messeae* Falleroni, 1926** (Figure 2e): The published information up to 1977 showed the occurrence of *An. messeae* in 13 of the 25 provinces, and the more recent records added nine provinces to the distribution. The recent distribution of *An. messeae* includes 21 of the 25 provinces from the very south to the very north of Sweden. Medical importance: The epidemics of *Plasmodium vivax* malaria in the 19th century occurred in several regions of south and central Sweden where *An. atroparvus* were missing, and most likely *An messeae* was the main vector in major parts of the country (Jaenson *et al.*, 1986a).

***Anopheles (Anopheles) plumbeus* Stephens, 1828** (Figure 2f): The published information up to 1977 showed the occurrence of *An. plumbeus* in one of the 25 provinces. The more recent information confirms the occurrence in the province of Skåne in the very south of Sweden.

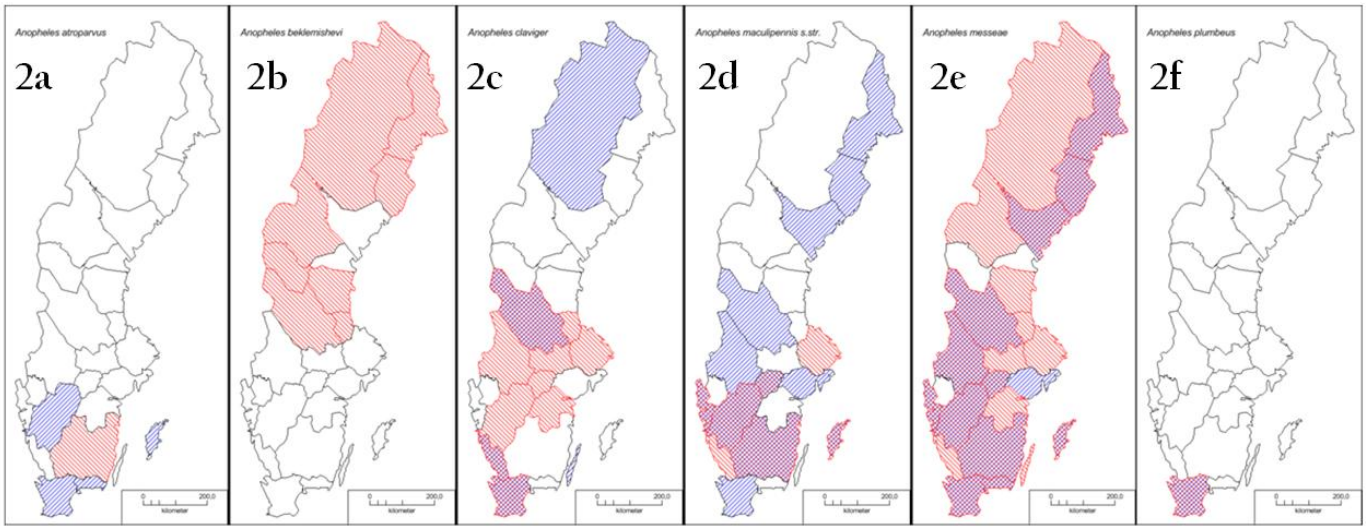

Figure 2. The Swedish province distribution of a) *Anopheles (Anopheles) atroparvus*, b) *Anopheles (Anopheles) beklemishevi*, c) *Anopheles (Anopheles) claviger*, d) *Anopheles (Anopheles) maculipennis sensu stricto*, e) *Anopheles (Anopheles) messeae*, and f) *Anopheles (Anopheles) plumbeus*. Legends: ▨ species records from Dahl (1977), ▨ species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

Genus *Aedes*

The genus *Aedes* is represented by three *Aedes (Aedes)* species, 24 *Aedes (Ochlerotatus)* species, one *Aedes (Aedimorphus)* species, one *Aedes (Finlaya)* species, and two *Aedes (Rusticoides)* species in Sweden (Table 1).

***Aedes (Aedes) cinereus* Meigen, 1818** (Figure 3a): The published information up to 1977 showed the occurrence of *Ae. cinereus* in 10 provinces covering the whole country. The more recent information added nine more provinces to the distribution, and show that the species occurs in the whole country. Medical importance: The mosquito-borne Sindbis virus (Lundström & Pfeffer, 2010), causing rash and polyarthritis in humans (Espmark & Niklasson, 1984, Niklasson *et al*., 1988, Kurkela *et al*., 2004, 2005), is a bird-associated zoonosis with *Cx. torrentium* as its main enzootic vector (Francy *et al*., 1989, Lundström *et al*., 1990). Transmission of Sindbis virus to humans requires a link-vector that feeds on both birds and humans (Lundström, 1994, 1999). Sindbis virus has been repeatedly isolated from *Ae. cinereus* in Sweden (Francy *et al*., 1989), and in experimental infection and transmission studies it was shown to be susceptible to the virus and infected *Ae. cinereus* was able to transmit Sindbis virus (Turell *et al*., 1990). In addition, recent studies have defined *Ae. cinereus* as one of the potential vectors of *Francisella tularensis holarctica*, the bacteria causing tularemia in humans and animals (Lundström *et al*., 2011, Rydén *et al*., 2011).

***Aedes (Aedes) geminus* Peus, 1970** (Figure 3b): The published information up to 1977 provided records of *Ae. geminus* in two provinces in southern Sweden. The species was not recorded during the more recent inventories in Skåne, and other parts of southern Sweden. Further studies are warranted to verify if this species is part of the Swedish mosquito fauna.

***Aedes (Aedes) rossicus* Dolbeskin, Goritzkaja & Mitrofanova, 1930** (Figure 3c): The species was not included in the records for Sweden up to 1977, and it was first recorded from the province of Gästrikland in the middle of the 1980´s (Jaenson, 1986). The recent records for *Ae. rossicus* show occurrence in six provinces in southern and central Sweden, and in the province of Västerbotten.

***Aedes (Aedimorphus) vexans* (Meigen, 1830)** (Figure 3d): The published information up to 1977 provided records of the species in six provinces covering the whole country. More recent records provide evidence for a main distribution in southern and central Sweden, and in the province of Västerbotten. However, there are no recent records of *Ae. vexans* from the province of Lappland in the very north.

***Aedes (Finlaya) geniculatus* (Olivier, 1791)** (Figure 3e): The published information up to 1977 showed the occurrence of *Ae. geniculatus* only in the province of Skåne in the very south. The more recent information confirms the occurrence in the province of Skåne, and extends the distribution to a further six provinces, showing a recent distribution in seven provinces in the southern half of the country.

***Aedes (Ochlerotatus) annulipes* (Meigen, 1830)** (Figure 3f): The published information up to 1977 showed the occurrence of *Ae. annulipes* in five of the 25 provinces. The more recent information confirms the occurrence in three of these provinces and extends the distribution to a further nine provinces, showing a recent distribution in at least 13 provinces in the southern half of the country and along the northern part of the east coast of Sweden.

***Aedes (Ochlerotatus) cantans* (Meigen, 1818)** (Figure 4a): The published information up to 1977 showed occurrence of *Ae. cantans* in eight of the 25 provinces. The more recent information confirms the occurrence in four of these provinces and extends the distribution to a further 12 provinces, showing a recent distribution in at least 16 provinces in the southern half of the country and along the northern part of the east coast of Sweden. There are no recent records from the province of Lappland in the very north.

***Aedes (Ochlerotatus) caspius* (Pallas, 1771)** (Figure 4b): The published information up to 1977 showed the occurrence of *Ae. caspius* in three of the 25 provinces, and only in the very southern part of Sweden. The more recent information confirms the occurrence in two of these provinces and extends the distribution to a further two provinces along the east coast of central Sweden, showing a recent mainly coastal distribution in four provinces in the southern half of the country.

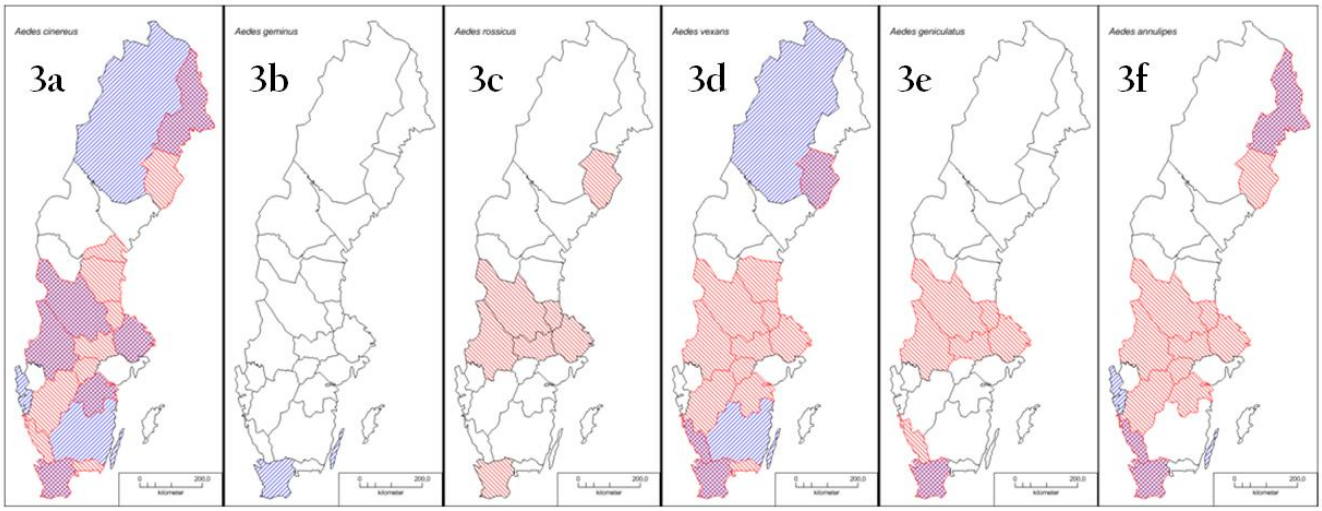

Figure 3. The Swedish province distribution of a) *Aedes (Aedes) cinereus*, b) *Aedes (Aedes) geminus*, c) *Aedes (Aedes) rossicus*, d) *Aedes (Aedimorphus) vexans*, e) *Aedes (Finlaya) geniculatus*, and f) *Aedes (Ochlerotatus) annulipes*. **Legends**: ▨ species records from Dahl (1977), ▨ species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

***Aedes (Ochlerotatus) cataphylla* (Dyar, 1916)** (Figure 4c): The published information up to 1977 showed the occurrence of *Ae. cataphylla* in eight provinces from the south to the very north. The more recent information confirms the occurrence in three of these provinces and extends the distribution to a further seven provinces, showing a recent distribution in the southern half of the country.

***Aedes (Ochlerotatus) communis* (De Geer, 1776)** (Figure 4d): The published information up to 1977 showed the occurrence of *Ae. communis* in 12 provinces over the whole country. The more recent information confirms the occurrence in six of these provinces and extends the distribution to a further 10 provinces, showing that *Ae. communis* is widespread and abundant over the whole country. Medical importance: Virus isolation from field collected specimens show that *Ae. communis* is a potential vector of Inkoo virus (Francy *et al.*, 1989), but the vector competence have not been experimentally verified (Lundström, 1994).
distribution in almost all provinces covering the whole country.

***Aedes (Ochlerotatus) dorsalis* (Meigen, 1830)** (Figure 5b): The published information up to 1977 showed the occurrence of *Ae. dorsalis* in five provinces. The more recent information confirms the occurrence in two of these provinces and extends the distribution to a further two provinces on the east coast of central Sweden. The recent distribution of *Ae. dorsalis* includes coastal areas in the southern half of the country.

***Aedes (Ochlerotatus) euedes* (Howard, Dyar & Knab, 1912)** (Figure 5c): The species *Ae. euedes* was not recorded in Sweden up to 1977, but was reported in one of the 25 provinces in recent years (Blackmore & Dahl, 2001). The record is from the province of Gästrikland, near Lake Fängsjön, and in this same area we are running our bi-weekly mosquito monitoring programme since 2001. However, our continued inventories in the area for 12 years (2000-2011) have not been able to confirm the occurrence of this species, although very large number of mosquitoes have been collected and identified (Table 1).

***Aedes (Ochlerotatus) cyprius* (Ludlow, 1919)** (Figure 4e): The published information up to 1977 showed the occurrence of *Ae. cyprius* in seven provinces in southern, central and northern Sweden. However, presence of this species is not confirmed in the more recent studies, and more studies are warranted to confirm if it is part of the Swedish mosquito fauna.

***Aedes (Ochlerotatus) detritus* (Haliday, 1833)** (Figure 4f): The published information up to 1977 showed the occurrence of *Ae. detritus* in two provinces of the very south. The more recent information confirms the occurrence in the Halland and the Skåne provinces.

***Aedes (Ochlerotatus) diantaeus* (Howard, Dyar & Knab, 1912)** (Figure 5a): The published information up to 1977 showed the occurrence of *Ae. diantaeus* in five provinces from north to south. The more recent information confirms the occurrence in three of these provinces and extends the distribution to a further 13 provinces, showing a recent

***Aedes (Ochlerotatus) excrucians* (Walker, 1856)** (Figure 5d): The published information up to 1977 showed the occurrence of *Ae. excrucians* in 12 provinces over the whole of Sweden. The more recent information confirms the occurrence in two of these provinces and extends the distribution to four further provinces, showing a recent distribution in central and northern Sweden.

***Aedes (Ochlerotatus) flavescens* (Muller, 1764)** (Figure 5e): The published information up to 1977 showed the occurrence of *Ae. flavescens* in six provinces. The more recent information confirmed the occurrence in one of these provinces, and extends the distribution to a further three provinces. It appears to be distributed mainly in the southern half of the country, but is not a common species.

***Aedes (Ochlerotatus) hexodontus* (Dyar, 1916)** (Figure 5f): The published information up to 1977 showed the occurrence of *Ae. hexodontus* in three provinces. The more recent information confirms the occurrence in one of these provinces, and extends the distribution to a further two provinces, showing a recent distribution in mainly the northern half of Sweden.

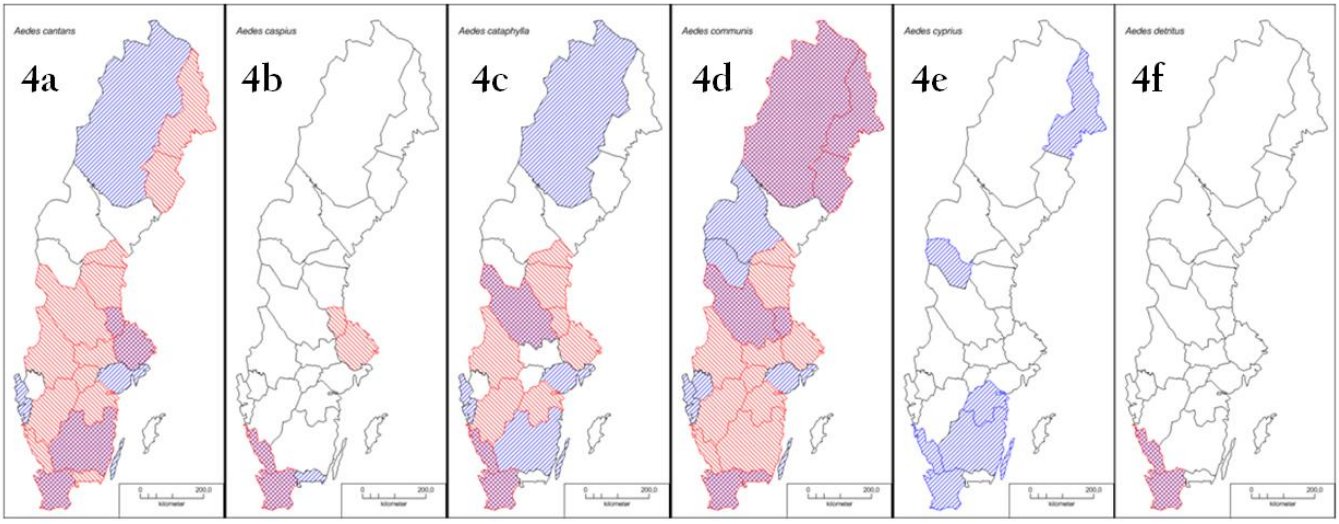

Figure 4. The Swedish province distribution of a) *Aedes (Ochlerotatus) cantans*, b) *Aedes (Ochlerotatus) caspius*, c) *Aedes (Ochlerotatus) cataphylla*, d) *Aedes (Ochlerotatus) communis*, e) *Aedes (Ochlerotatus) cyprius*, and f) *Aedes (Ochlerotatus) detritus*. **Legends**: ▨ species records from Dahl (1977), ▨ species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

***Aedes (Ochlerotatus) impiger* (Walker, 1848)** (Figure 6a): The published information up to 1977 showed the occurrence of *Ae. impiger* in the province of Lappland in the very north. The more recent information confirms the occurrence in the province of Lappland, and show that this is a tundra species occurring only in the very northern part of the country.

***Aedes (Ochleratutus) intrudens* (Dyar, 1919)** (Figure 6b): The published information up to 1977 showed the occurrence of *Ae. intrudens* in six provinces over the whole country. The more recent information confirms the occurrence in five provinces, extends the distribution to a further nine provinces, and shows that the species occurs in the whole of Sweden.

***Aedes (Ochlerotatus) leucomelas* Meigen, 1804)** (Figure 6c): The published information up to 1977 showed the occurrence of *Ae. leucomelas* in five provinces in southern Sweden. The more recent information confirms the occurrence in one of these provinces, and extends the distribution to a further five provinces, showing a recent distribution in major parts of southern and central Sweden.

***Aedes (Ochlerotatus) nigrinus* (Eckstein, 1918)** (Figure 6d): The first record of this species in Sweden is from a nationwide surveillance in 2012. It was recorded in the province of Norrbotten, the province of Småland, and the province of Halland. These recent data show that *Ae. nigrinus* has wide a distribution in Sweden, although it is a rather uncommon species.

***Aedes (Ochlerotatus) nigripes* (Zetterstedt, 1838)** (Figure 6e): The published information up to 1977 showed the occurrence of *Ae. nigripes* in two provinces in northern and central Sweden. The more recent information confirms the occurrence only in the province of Lappland. Apparently the recent distribution includes only the northern part of Sweden.

***Aedes (Ochlerotatus) pionips* (Dyar, 1919)** (Figure 6f): The published information up to 1977 showed the occurrence of *Ae. pionips* in the very northern provinces of Lappland and Norrbotten. The more recent information confirms the occurrence in the province of Lappland, and extends the distribution to one province in central Sweden and one province in the very south. The recent distribution of *Ae. pionips* includes the whole of Sweden although it appears to be a rather uncommon species.

***Aedes (Ochlerotatus) pullatus* (Coquillett, 1904)** (Figure 7a): The published information up to 1977 showed the occurrence of *Ae. pullatus* in the very northern province of Lappland. The more recent information confirms the occurrence in the province of Lappland, and extends the distribution to one province in central Sweden and one province in the very south. The recent distribution of *Ae. pullatus* includes the whole of Sweden although it appears to be a rather uncommon species.

***Aedes (Ochlerotatus) punctodes* (Dyar, 1922)** (Figure 7b): The published information up to 1977 showed the occurrence of *Ae. punctodes* in the very northern provinces of Lappland and Norrbotten. The more recent information confirms the occurrence in the province of Lappland, and show that the distribution is restricted to northernmost Sweden.

***Aedes (Ochlerotatus) punctor* (Kirby, 1827)** (Figure 7c): The published information up to 1977 showed the occurrence of *Ae. punctor* in 14 of the 25 provinces. The more recent information confirms the occurrence in nine of these provinces and extends the distribution to a further eight provinces, showing a recent distribution in at least 17 provinces over the whole country. *Ae. punctor* is one of the most common and widespread species in Sweden. Medical importance: *Ae. punctor* is a common mosquito in forested areas in early summer, and virus isolation from specimens from the province of Lappland show it is a potential vector of Inkoo virus (Lundström, 1994).

***Aedes (Ochlerotatus) riparius* (Dyar & Knab, 1907)** (Figure 7d): The published information up to 1977 showed the occurrence of *Ae. riparius* in four of the 25 provinces. However, presence of this species is not confirmed in the more recent studies.

Aedes (Ochlerotatus) sticticus (Meigen, 1838) (Figure 7e): The published information up to 1977 showed the occurrence of *Ae. sticticus* in two of the 25 provinces. The more recent information confirms the occurrence in these two provinces and extends the distribution to a further 10 provinces, showing a recent distribution in at least 12 provinces in the southern half of Sweden. The distribution of

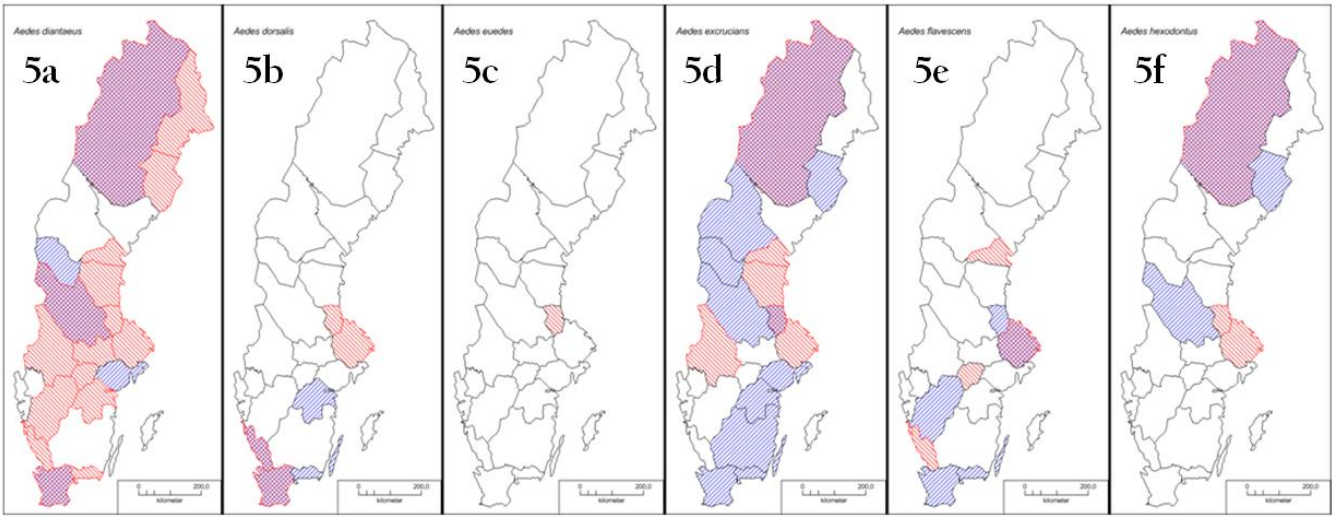

Figure 5. The Swedish province distribution of a) *Aedes (Ochlerotatus) diantaeus*, b) *Aedes (Ochlerotatus) dorsalis*, c) *Aedes (Ochlerotatus) euedes*, d) *Aedes (Ochlerotatus) excrucians*, e) *Aedes (Ochlerotatus) flavescens*, and f) *Aedes (Ochlerotatus) hexodontus*. **Legends**: species records from Dahl (1977), species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

this flood-water species is highly dependent on the occurrence of floods during the vegetation season, and it is expected to strongly expand its distribution in relation to a changing climate with warmer summers and increased precipitation (Schäfer & Lundström, 2009). Medical importance: This is the main nuisance mosquito species in Sweden occurring in massive numbers near some temporary flooded areas (Schäfer *et al*., 2008, Schäfer & Lundström, 2009), and it is an important nuisance species also in Germany, Serbia and Canada (Becker *et al*., 2010). In addition, *Ae. sticticus* is one of the potential mosquito vectors of *Francisella tularensis holarctica*, a bacterium causing Tularemia in humans and animals, and it could become infected already as larvae (Lundström *et al*., 2011, Rydén *et al*., 2012).

***Aedes (Rusticoides) refiki* (Medschid, 1928)** (Figure 7f): The published information up to 1977 showed the occurrence of *Ae. refiki* only in the province of Öland. Our recent surveillance provided one specimen of the species in the same province, confirming that this rare species is part of the present Swedish mosquito fauna.

***Aedes (Rusticoides) rusticus* (Rossi, 1790)** (Figure 8a): The published information up to 1977 showed the occurrence of *Ae. rusticus* in two of the 25 provinces. The more recent information confirms the occurrence in one of these provinces, showing a recent distribution only in the southernmost part of Sweden.

Genus *Coquillettidia*

Only one *Coquillettidia (Coquillettidia)* species is recorded in Sweden (Table 1).

***Coquillettidia (Coquillettidia) richiardii* (Ficalbi, 1889)** (Figure 8b): The published information up to 1977 showed occurrence of *Cq. richiardii* in six of the 25 provinces. The more recent information confirms the occurrence in two of these provinces, and extends the recorded distribution in a further 13, showing a recent distribution in 15 provinces in the southern half of the country, and along the northeast coast.

Genus *Culex*

The genus *Culex* is represented by two *Culex (Culex)* species, and one *Culex (Neoculex)* species in Sweden (Table 1).

***Culex (Culex) pipiens* Linnaeus, 1758 *sensu latu*.** Based on morphology, females and larvae of *Cx. pipiens s. str.* cannot be securely differentiated from *Cx. torrentium*, and therefore secure morphological species identification is performed on males only (Onyeka, 1982). The older published information may therefore not have separated the species but routinely called them *Cx. pipiens*, and we decided to only use records based on identified males for these two species. Hesson *et al*. (2010) developed a specific molecular method for identification of all life stages of *Cx. pipiens* and *Cx. torrentium*, providing the tool for large scale inventory of the two species in Sweden and other parts of Europe.

Culex (Culex) pipiens* Linnaeus, 1758 *sensu strictu (Figure 8c): The published records of male *Cx. pipiens s. str.* up to 1977 showed occurrence in 10 of the 25 provinces. Hesson *et al*. (2011) identified *Culex* larvae collected over major parts of Sweden to species, and convincingly showed the recent distribution of *Cx. pipiens* in Sweden. This recent information confirms the occurrence in seven of these provinces and extends the distribution to a further seven provinces, showing a recent distribution in at least 14 provinces over the whole country. Medical importance: Sindbis virus (Lundström & Pfeffer, 2010), has been repeatedly isolated from a mixture of *Cx. pipiens* and/or *Cx. torrentium* in Sweden (Francy *et al*., 1989). However, in experimental infection and transmission studies, *Cx. pipiens* was shown to be refractory to Sindbis virus if not infected by very high dosage, and few infected *Cx. pipiens* were able to transmit the virus to susceptible hosts (Lundström *et al*., 1990, Lundström, 1994). So far, there is a lack of information on the occurrence of Sindbis virus in securely identified *Cx. pipiens* in Europe (Jöst *et al*., 2010), although there are a few isolates from this species in South Africa and in Israel (McIntosh *et al*., 1967, 1976, Nir *et al*., 1972). Thus, at present *Cx. pipiens* is probably not an important vector for Sindbis virus in Sweden.

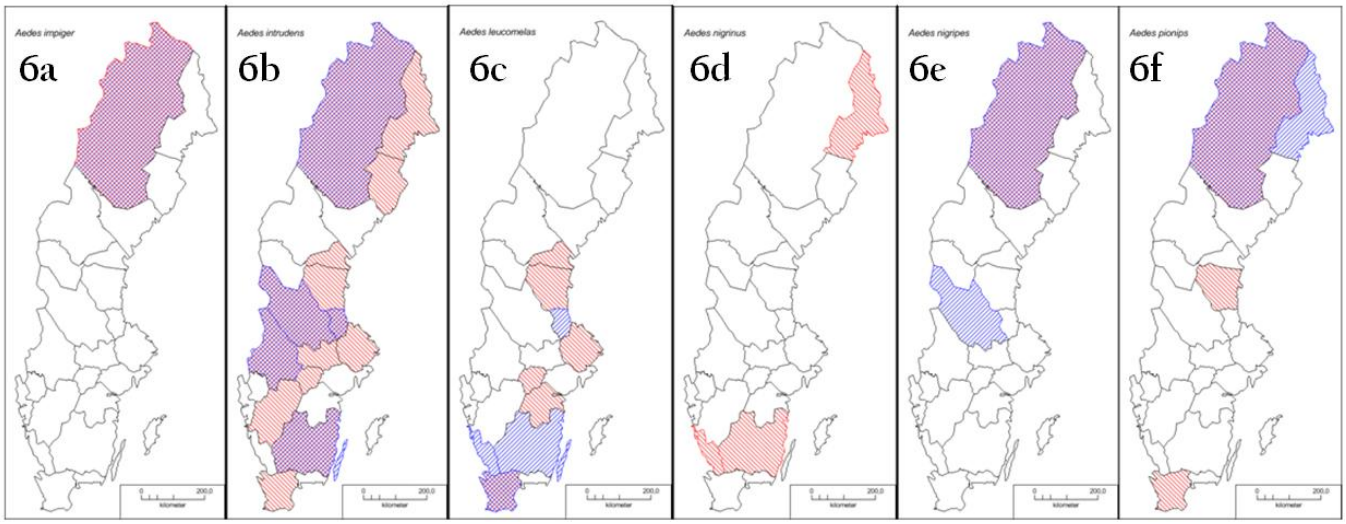

Figure 6. The Swedish province distribution of a) (*Aedes (Ochlerotatus) impiger*, b) *Aedes (Ochleratutus) intrudens*, c) *Aedes (Ochlerotatus) leucomelas*, d) *Aedes (Ochlerotatus) nigrinus*; e) *Aedes (Ochlerotatus) nigripes*, and f) *Aedes (Ochlerotatus) pionips*. **Legends**: ▨ species records from Dahl (1977), ▨ species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

In southern Europe, *Cx. pipiens* is considered a vector for West Nile virus based on isolation of virus from field collected specimens (Parreira *et al*., 2007, Papa *et al*., 2013), and a modest experimental vector competence (Balenghien *et al*., 2008). However, West Nile virus requires long periods of temperature above 30°C for efficient transmission by vector mosquitoes. The extrinsic incubation period (the time it takes for the virus infection to pass the mosquito body and be transmissible by the mosquito saliva) for West Nile virus is about 4 weeks at 22°C and only 1 week at 32°C (Kilpatrick *et al*., 2008). Outbreaks in the Mediterranean required weeks of elevated temperatures, more than 5°C above their normal summer temperatures (Paz *et al*., 2013), which is summer temperatures rarely if ever recorded in Sweden. Thus, a dramatic and persistent increase in summer temperature need to occur before *Cx. pipiens* may become an important West Nile virus vector in Sweden.

Culex (Culex) torrentium* Martini, 1925 *sensu strictu (Figure 8d): The published records of male *Cx. torrentium s. str.* up to 1977 showed occurrence in three of the 25 provinces. Hesson *et al*. (2011) identified *Culex* larvae collected over major parts of Sweden to species, and convincingly showed the recent distribution of *Cx. torrentium* in Sweden. This recent information confirms the occurrence in all these provinces and extends the distribution to a further 17 provinces, showing a recent distribution in 20 provinces over the whole country. Thus, this is the most common and widely distributed *Culex* species in Sweden. Medical importance: Sindbis virus has been repeatedly isolated from a mixture of *Cx. pipiens* and/or *Cx. torrentium* in Sweden (Francy *et al*., 1989). In experimental infection and transmission studies *Cx. torrentium* was shown to be extremely susceptible to Sindbis virus even at very low dosage, and close to all infected *Cx. torrentium* were able to transmit the virus to susceptible hosts (Lundström *et al*., 1990, Lundström, 1994). So far, there is a lack of information on the occurrence of Sindbis virus in securely identified *Cx. torrentium* in Europe (Jöst *et al*., 2010). However, all available information indicate that *Cx. torrentium* is the enzootic vector for Sindbis virus in Sweden, and probably also in other parts of Europe (Francy *et al*., 1989, Lundström *et al*., 1990, Lundström, 1994, Hesson *et al*., 2011, 2013).

***Culex (Neoculex) territans* Walker, 1856** (Figure 8e): The published information up to 1977 showed the occurrence of *Cx. territans* in one of the 25 provinces. The more recent information extends the distribution to a further two provinces, showing a recent distribution in central Sweden. However, this species might be underrepresented since the adults are difficult to catch in carbon dioxide baited traps such as CDC-traps and counter-flow traps.

Genus *Culiseta*

The genus *Culiseta* is represented by three *Culiseta (Culicella)* species, and four *Culiseta (Culiseta)* species in Sweden (Table 1).

***Culiseta (Culicella) fumipennis* (Stephens, 1825)** (Figure 8f): The published information up to 1977 showed the occurrence of *Cs. fumipennis* in two of the 25 provinces. The more recent information confirms the occurrence in one of these provinces, showing a recent distribution only in the province of Skåne in southern Sweden.

***Culiseta (Culicella) morsitans* (Theobald, 1901)** (Figure 9a): The published information up to 1977 showed the occurrence of *Cs. morsitans* in seven of the 25 provinces. The more recent information confirms the occurrence in four of these provinces and extends the distribution to a further 10 provinces, showing a recent distribution in 14 provinces in the southern half of the country, and along the northeast cost of Sweden. Medical importance: Sindbis virus has been repeatedly isolated from *Cs. morsitans* in Sweden (Francy *et al*., 1989). However, no experimental infection and transmission studies have been performed with this species, so the eventual role as additional enzootic vector is unclear (Lundström, 1994).

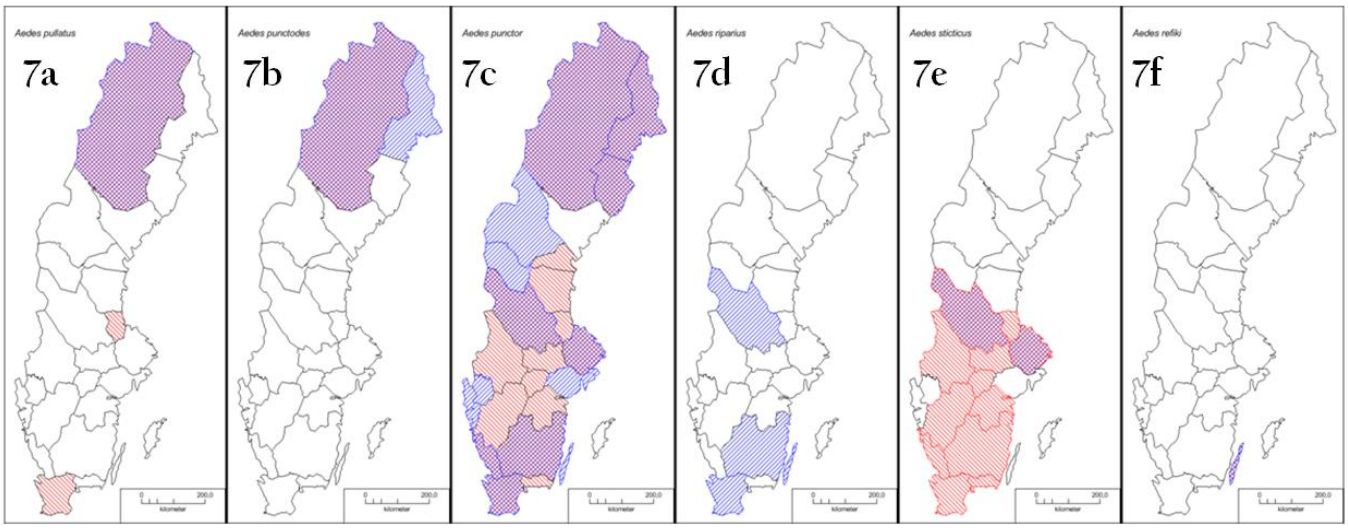

Figure 7. The Swedish province distribution of a) *Aedes (Ochlerotatus) pullatus*, b) *Aedes (Ochlerotatus) punctodes*, c) *Aedes (Ochlerotatus) punctor*, d) *Aedes (Ochlerotatus) riparius*, e) *Aedes (Ochlerotatus) sticticus*, and f) *Aedes (Rusticoides) refiki*. **Legends**: species records from Dahl (1977), species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

***Culiseta (Culicella) ochroptera* (Peus, 1935)** (Figure 9b): The species was not included in the records for Sweden up to 1977, and it was first recorded from the province of Gästrikland in the early 1980´s (Jaenson, 1984). The recent records for *Cs. ochroptera* show occurrence in 12 provinces in southern and central Sweden, and along the northeast cost of Sweden.

***Culiseta (Culiseta) alaskaensis* (Ludlow, 1906)** (Figure 9c): The published information up to 1977 showed the occurrence of *Cs. alaskaensis* in eight of the 25 provinces. The more recent information confirms the occurrence in five of these provinces and extends the distribution to a further five provinces, showing a recent distribution in 10 provinces over the whole country.

***Culiseta (Culiseta) annulata* (Schrank, 1776)** (Figure 9d): The published information up to 1977 showed the occurrence of *Cs. annulata* in six of the 25 provinces. The more recent information confirms the occurrence in three of these provinces and extends the distribution to a further six provinces, showing a recent distribution in nine provinces in the southern half of Sweden.

***Culiseta (Culiseta) bergrothi* (Edwards, 1921)** (Figure 9e): The published information up to 1977 showed the occurrence of *Cs. bergrothi* in six of the 25 provinces. The more recent information confirms the occurrence in these six provinces and extends the distribution to a further six provinces, showing a recent distribution in 12 provinces over the whole country.

***Culiseta (Culiseta) subochrea* (Edwards, 1921)** (Figure 9f: The published information up to 1977 showed the occurrence of *Cs. subochrea* in one of the 25 provinces. However, presence of this species is not confirmed in the more recent studies.

Discussion

Recent decades of mosquito research in Sweden have provided an immense amount of data on the mosquito species occurring in the country, and on their respective geographic distribution. For the majority of species the combination of data from Dahl (1977), and the past 36 years of distribution data, provides an improved geographic sampling coverage, and a more reliable understanding of their respective geographic distribution patterns within Sweden. However, for some rare species, such as *Cs. fumipennis* and *Cx. territans*, it is evident that more sampling, and probably highly focused sampling, will be needed to even find the species. Dahl (1977) listed *Cs. fumipennis* in the provinces of Skåne and Östergötland, and the authors managed to find five specimens in the Egeside area in Skåne in 1998 (Schäfer & Lundström, 2001). However, in the present meta-study we provide data from four even more recent years of complete season sampling within the same area, and not a single *Cs. fumipennis* was found. Similarly, Dahl (1977) listed *Cx. territans* in the province of Skåne, and Jaenson *et al.* (1986b) listed the species in the province of Hälsingland. However, massive amounts of mosquito sampling 2001-2012, and the species identification of 1,251,668 individual mosquitoes, have only provided one single record of *Cx. territans* (near Avesta in the province of Dalarna). Jaenson *et al.* (1986b) managed to find more specimens of *Cx. territans* by using larval sampling and identification, and this is probably the best method for detecting the species.

The geographic distribution of the floodwater mosquito *Ae. sticticus* is increasing in Sweden, and this geographic expansion is related to a changing climate with warmer and longer summers, increased precipitation, and higher frequency of heavy rain (Schäfer & Lundström, 2009). We anticipate that other mosquito species will also react to the changing climate, but since the sensitivity to environmental factors may vary between species it is difficult to draw more general conclusions without more data. However, it is possible that changing climate is one of the explanations for a difference between the historical and the present geographic records of mosquito species in Sweden.

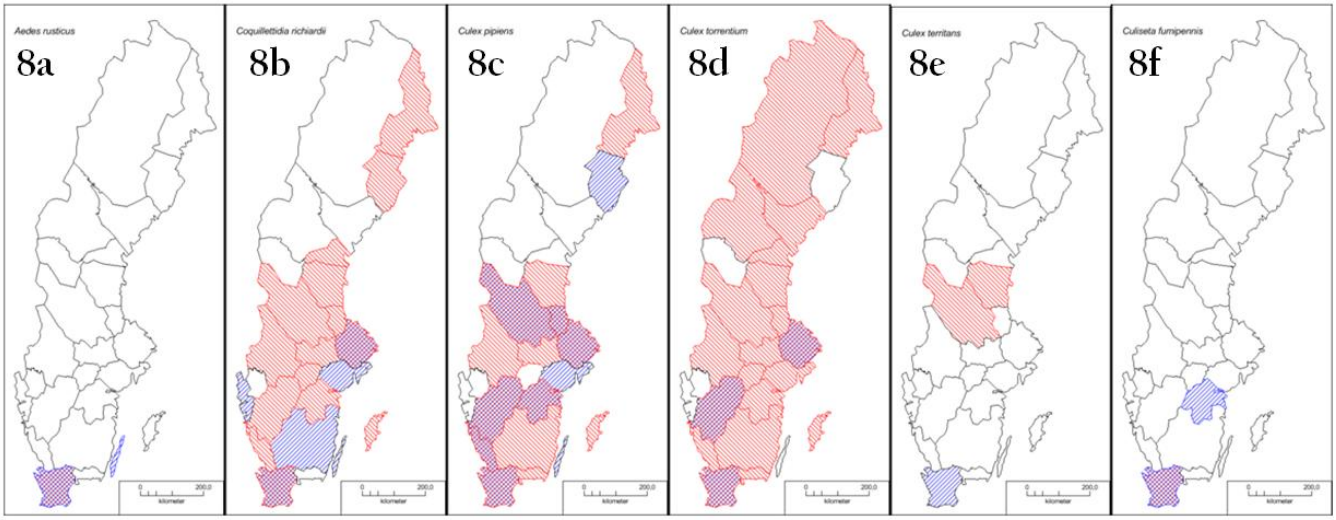

Figure 8. The Swedish province distribution of a) *Aedes (Rusticoides) rusticus*, b) *Coquillettidia (Coquillettidia) richiardii*, c) *Culex (Culex) pipiens* sensu stricto, d) *Culex (Culex) torrentium sensu stricto*, e) *Culex (Neoculex) territans*, and f) *Culiseta (Culicella) fumipennis* (Stephens, 1825). **Legends**: ▨ species records from Dahl (1977), ▨ species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

The *Ae. annulipes* group of mosquitoes in Sweden includes the species *Ae. annulipes*, *Ae. cantans*, *Ae. cyprius*, *Ae. euedes*, *Ae. excrucians*, *Ae. flavescens*, and *Ae. riparius* (Becker *et al.*, 2010). Only Dahl (1977) provides records of *Ae. cyprius* and *Ae. riparius*, and neither of these species were observed in recent decades. Similarly, only Blackmore & Dahl (2001) provide a record of *Ae. euedes*, caught near Lake Fängsjön, in the province of Gästrikland. However, our massive full season sampling in the same general area 2000 – 2012 has not provided any additional specimens of *Ae. euedes*. We conclude that before a final conclusion on the *Ae. annulipes* group of species occurring in Sweden can be drawn, more focused field sampling followed by development of molecular methods for identification will be needed. Recently, molecular methods were developed based on genotypic primers and SNP in the COI gene for PCR-based identification of 14 mosquito species occurring in Sweden (Engdahl *et al.*, 2013), and similar methods could be developed also for other species.

The subgenus *Aedes (Aedes)* mosquitoes include the species *Ae. geminus*, *Ae. rossicus*, and *Ae. cinereus* (Becker *et al.*, 2010). The species *Ae. cinereus* and *Ae. geminus* were listed by Dahl (1977), while *Ae. rossicus* was first recorded in Sweden by Jaenson (1986). Our recent surveillance show that *Ae. cinereus* is a common and widespread species, and that also *Ae. rossicus* is fairly widespread and abundant in some areas, while there is no recent records of *Ae. geminus*. However, in our surveillance only female mosquitoes have been sampled and identified, while *Ae. geminus* can be separated from the other two closely related species by morphological characters of the males. Thus, females of *Ae. geminus* may potentially have been identified as either of the neighbouring species. We conclude that further studies on the species in the subgenus *Aedes (Aedes)* in Sweden is warranted.

Another historically detected species that was not recorded in recent decades is *Cs. subochrea*. At present it is difficult to conclude whether it is part of the Swedish mosquito fauna. We are now looking forward to the results of the ongoing nationwide surveillance of the mosquito fauna (organised by Eric Blomgren and Anders Lindström) that has already provided records of *Ae. nigrinus* and *An. algeriensis* (not previously detected in Sweden), the continued full season surveillance in several areas (organised by Martina Schäfer and Jan O. Lundström), and other potential on-going study efforts in Sweden. In addition, more focused studies on specific groups of mosquitoes are needed, as for example studies like those by Jaenson *et al.* (1986a) and by Hesson *et al.* (2010, 2011, 2013), in which group-specific sampling and advanced identification methods were used for the morphologically cryptic species. Thus, for future studies it is suggested to focus on both developing molecular methods for specific, sensitive and time-efficient species identification, and on group-specific nationwide sampling of both adult and larval stages.

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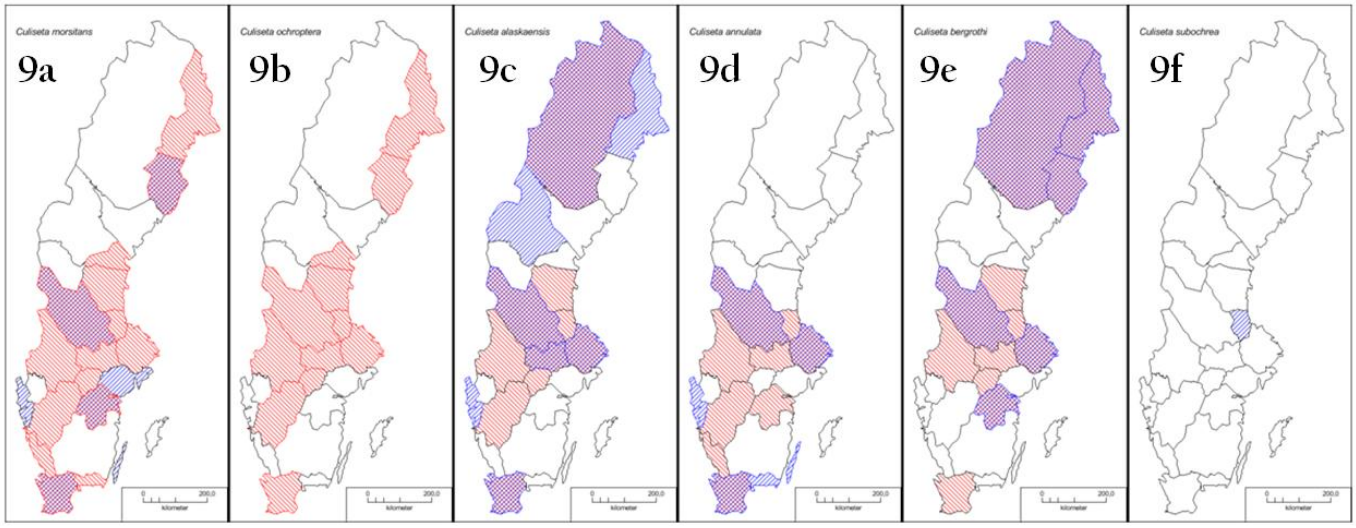

Figure 9. The Swedish province distribution of a) *Culiseta (Culicella) morsitans*, b) *Culiseta (Culicella) ochroptera*, c) *Culiseta (Culiseta) alaskaensis*, d) *Culiseta (Culiseta) annulata*, e) *Culiseta (Culiseta) bergrothi*, and f) *Culiseta (Culiseta) subochrea*. **Legends**: species records from Dahl (1977), species records during years 1978 to 2013, and the cross hatched area visualize the species was recorded during both time periods.

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