Pest occurrence of *Aedes rossicus* close to the Arctic Circle in northern Sweden

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**ABSTRACT:** Major nuisance species are found among the floodwater mosquitoes and snow-pool mosquitoes, with the former being the main reason for mosquito control in most areas. Nuisance species vary with the area, and previous reports from northern areas conclude that the nuisance is most often caused by snow-pool mosquitoes. We investigated the mosquito fauna and abundances of host-seeking females using CDC traps baited with carbon dioxide, in Övertorneå city near the Arctic Circle in northern Sweden, after earlier complaints about massive mosquito nuisance. The abundance of host-seeking female mosquitoes was high in 2014, with a maximum of ~15,400 individuals per CDC trap night, of which 89% was the floodwater mosquito *Aedes rossicus*. Surprisingly, the main nuisance species was a floodwater mosquito, occurring at the northernmost location it has ever been recorded in Sweden. Our report is probably the first documentation of such large numbers of *Aedes rossicus* in any locality and probably the first documentation of a severe floodwater mosquito nuisance near the Arctic Circle. Given the historical data on river discharge in the area, the nuisance is recurrent. We conclude that in northern localities, as well as in more southern localities, production of floodwater mosquitoes is a natural component of the floodplain fauna of rivers with a fluctuating water flow regime. Also, the floodwater mosquitoes *Aedes sticticus* and *Aedes vexans* were found north of their formerly known distribution in Sweden. *Journal of Vector Ecology* 43 (1): 36-43. 2018.

**Keyword Index:** Culicidae, rossicus, sticticus, vexans, floodwater mosquitoes, mosquito nuisance.

**INTRODUCTION**

Mosquitoes can be a major pest to humans and animals, both as vectors of pathogens and as a cause of nuisance. Nuisance species often occur in very large numbers and attack with ferocity, with a great impact on everyday life and outdoor activities. In Europe, the most common nuisance species belong to the group of floodwater mosquitoes and occur in temporary flooded riverine and coastal meadows. Floodwater mosquitoes oviposit on soil in flood-prone areas, eggs remain dormant and viable for several years forming an egg-bank, and eggs hatch to larvae when flooded during spring and summer if water temperature is sufficient (Becker et al. 2010). These mosquitoes can have several generations in a season, adding to the numbers and extending the time period of nuisance to include all summer months and part of the autumn.

The Swedish mosquito fauna includes 50 species, of which nine species of the genus *Aedes* fulfil the criteria for characterization as floodwater mosquitoes (Functional Group (FG) 2B) (Schäfer et al. 2004, Lundström et al. 2013, Hesson et al. 2016). Several of the floodwater mosquito species recorded for Sweden are known to cause severe nuisance in many European countries (Becker et al. 2010, Merdic and Lovakovic 2001, Minar et al. 2001, Schäfer et al. 2008, Berec et al. 2014). The floodwater mosquitoes *Aedes vexans*, *Aedes caspius*, and *Aedes sticticus* are the major cause of nuisance in Serbia, Croatia, and Montenegro. On the Mediterranean Coast of the French Riviera, *Ae. caspius* is the main cause of nuisance, while both *Ae. caspius* and *Aedes detritus* are the main cause of nuisance on the French Atlantic coast. *Ae. vexans* and *Ae. sticticus* are the main nuisance species in Germany, Poland, Czech Republic, Switzerland, and Austria, as well as in other Central European countries. Although nine species of floodwater mosquitoes are reported from Sweden, only the species *Ae. sticticus* has been reported to cause massive nuisance (Schäfer and Lundström 2009, Schäfer and Lundström 2014), and this has only been reported in the southern half of Sweden. In northern Sweden and Scandinavia, the mosquito fauna is instead dominated by snow-pool mosquitoes (Mehl et al. 1983; Utrio 1979; Schäfer and Lundström 2001).

Several of the floodwater mosquitoes reported to cause severe nuisance in Europe have the capacity of long distance flight, extending 11 km or more from the larval habitats in temporary flooded wet meadows (Bogojevic et al. 2011). Therefore, the massive numbers of host-seeking females will affect humans in surrounding areas that are many times larger than the larval habitats. Thus, the mosquito nuisance becomes a major problem for inhabitants and businesses that are quite distant from the temporary flooded wetlands.

In 2013, the year before the study was commenced, the authors were contacted by representatives of the Övertorneå municipality, describing serious mosquito nuisance problems in and around Övertorneå city, 17 km south of the Arctic Circle in northern Sweden. The described magnitude of the mosquito nuisance and the behavior of the mosquitoes suggested it might be *Ae. sticticus*, however, the affected area is located about 500 km north of the known distribution of the species. Therefore, the aim of this study was to identify the cause of the mosquito nuisance problems that occurred in Övertorneå city and to describe the seasonality, abundance, and species composition of the mosquitoes in the area.
MATERIALS AND METHODS

Study sites

Övertorneå city is situated by the River Torneälven, which is the northernmost major river in Sweden (Figure 1). Along its lower stretches, the river forms a floodplain area of variable size and shape that stretches into both Sweden and Finland. The River Torneälven is the only unregulated major river in Sweden, thus it has a natural hydrology with seasonal water flow fluctuations due to melting snow and rain, inducing recurrent flooding of the floodplain area.

Four study sites were selected in or near Övertorneå city, all in close proximity to riverine areas prone to flooding during the vegetation season (Figure 1). Study site Ruskola is located just south of the city, very near to human settlements, and a little further away from temporary flooded areas compared to the other sites. West of the city is a small lake connected to River Torneälven and hence affected by its fluctuations. Study site Ekopark is located between this lake and the city. Study site Kuiva is located 2 km northwest of the city, in a smaller area partly covered with shrubs and grassy areas directly affected by the river. Study site SJ is just east of the city, also close to human settlement. The longest distance between study sites is about 2.8 km, between Kuiva and Ruskola. All four sites include vegetation with the typical sedges (Carex spp) and grasses (Calamagrostis spp) interspersed with tufts of bushes (Salix spp) in the open parts and with mainly birch (Betula sp) and some alder (Alnus sp) in the more forested parts.

Female mosquito sampling

Mosquitoes were collected with CDC miniature light traps baited with dry ice in the four study sites during 2014. One trap per site was hung out in the afternoon and retrieved the following morning, during June 26 (week 26), July 4 (week 27), July 17 (week 29), July 31 (week 31), and August 15 (week 33). Due to technical problems, sampling was not performed at Kuiva and Ekopark during week 29.

The mosquitoes were sorted from other arthropods caught in the trap, then weighed, using a high accuracy digital scale (0.01g), to calculate the total number of mosquitoes in catches that contained over 200 mosquitoes. The total number of mosquitoes was estimated by weighing 4x50 mosquitoes, calculating the mean weight of these batches and then dividing the mean weight by the number of mosquitoes in each batch (50). The result was the mean weight of each mosquito, and by dividing the weight of the total catch with this number, the total number of mosquitoes could be estimated. Mosquitoes were then stored at 25°C until morphological identification using the dichotomous key by Becker et al. (2010), under a stereo microscope illuminated with a cold light lamp. In each catch, up to 1,000 individual mosquitoes were identified, and bigger catches were extrapolated to the estimated total number of mosquitoes in that catch.

Mosquitoes were sorted into functional groups (FG) as defined by Schäfer et al. (2004) and Lundström et al. (2013). Here we use the trivial name “snow-pool mosquitoes” as a synonym for FG 2a, and the trivial name “floodwater mosquitoes” for FG 2b. Abundances were calculated as mean numbers of mosquitoes caught per trap and night (trap-night).

River discharge and air temperature

Data from The Swedish Meteorological and Hydrological Institute (www.smhi.se) on river discharge and air temperature were used as proxy for flood occurrence and mosquito production. Water discharge was extracted for Kukkolankoski Övre (daily values 2011-2015), while air temperature was extracted for Ylienjärvi (average daily values 2014), about 25 km north of Övertorneå city.

RESULTS

A total of over 117,000 mosquitoes of 14 species was caught during 18 trap-nights in June to August in the study areas. The most numerous species was the floodwater mosquito Aedes
Table 1. The species and the estimated number of mosquitoes collected in Övertorneå city, northern Sweden, using CDC-traps at four sites during a total of five trap-nights per site from June to August, 2014.

<table>
<thead>
<tr>
<th>Species / functional groups</th>
<th>Ekopark*</th>
<th>Kuiva*</th>
<th>Ruskola</th>
<th>SJ</th>
<th>Total</th>
<th>% of all mosquitoes</th>
<th>Mean per trap-night (max)</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Aedes cantans</em></td>
<td>59</td>
<td>11</td>
<td>84</td>
<td>118</td>
<td>273</td>
<td>&lt;1.0%</td>
<td>51.1 (60)</td>
</tr>
<tr>
<td><em>Aedes communis</em></td>
<td>2,924</td>
<td>1,776</td>
<td>8,995</td>
<td>8,571</td>
<td>22,266</td>
<td>19.0%</td>
<td>1,237.0 (7506)</td>
</tr>
<tr>
<td><em>Aedes diantaeus</em></td>
<td>849</td>
<td>341</td>
<td>2,026</td>
<td>1,852</td>
<td>5,068</td>
<td>4.3%</td>
<td>281.5 (1422)</td>
</tr>
<tr>
<td><em>Aedes excrucians</em></td>
<td>113</td>
<td>46</td>
<td>321</td>
<td>228</td>
<td>708</td>
<td>&lt;1.0%</td>
<td>39.4 (219)</td>
</tr>
<tr>
<td><em>Aedes intrudens</em></td>
<td>3,829</td>
<td>5,322</td>
<td>8,040</td>
<td>6,187</td>
<td>23,379</td>
<td>19.9%</td>
<td>1,298.8 (6488)</td>
</tr>
<tr>
<td><em>Aedes punctor</em></td>
<td>326</td>
<td>118</td>
<td>705</td>
<td>1,135</td>
<td>2,465</td>
<td>2.1%</td>
<td>136.9 (1215)</td>
</tr>
<tr>
<td><strong>Snow-pool mosquitoes</strong></td>
<td>8,101</td>
<td>7,614</td>
<td>20,172</td>
<td>18,271</td>
<td>54,159</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Aedes cinereus</em></td>
<td>166</td>
<td>103</td>
<td>85</td>
<td>869</td>
<td>1,224</td>
<td>1.0%</td>
<td>68.0 (537)</td>
</tr>
<tr>
<td><em>Aedes nigrinus</em></td>
<td>15</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>16</td>
<td>&lt;1.0%</td>
<td>0.9 (15)</td>
</tr>
<tr>
<td><em>Aedes rossicus</em></td>
<td>15,760</td>
<td>10,838</td>
<td>4969</td>
<td>29,310</td>
<td>60,876</td>
<td>51.9%</td>
<td>3,382.0 (13675)</td>
</tr>
<tr>
<td><em>Aedes sticticus</em></td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>16</td>
<td>20</td>
<td>&lt;1.0%</td>
<td>1.1 (16)</td>
</tr>
<tr>
<td><em>Aedes vexans</em></td>
<td>7</td>
<td>2</td>
<td>3</td>
<td>30</td>
<td>43</td>
<td>&lt;1.0%</td>
<td>2.4 (15)</td>
</tr>
<tr>
<td><strong>Floodwater mosquitoes</strong></td>
<td>15,948</td>
<td>10,943</td>
<td>5,063</td>
<td>30,225</td>
<td>62,179</td>
<td></td>
<td></td>
</tr>
<tr>
<td><em>Culex pipiens/torrentium</em></td>
<td>5</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>5</td>
<td>&lt;1.0%</td>
<td>0.3 (3)</td>
</tr>
<tr>
<td><em>Culiseta bergrothi</em></td>
<td>9</td>
<td>0</td>
<td>33</td>
<td>0</td>
<td>42</td>
<td>&lt;1.0%</td>
<td>2.3 (26)</td>
</tr>
<tr>
<td><em>Culiseta morsitans</em></td>
<td>0</td>
<td>1</td>
<td>258</td>
<td>8</td>
<td>267</td>
<td>&lt;1.0%</td>
<td>14.8 (178)</td>
</tr>
<tr>
<td><strong>Other species</strong></td>
<td>14</td>
<td>1</td>
<td>291</td>
<td>8</td>
<td>314</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unidentified</td>
<td>351</td>
<td>229</td>
<td>82</td>
<td>0</td>
<td>661</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>24,414</td>
<td>18,787</td>
<td>25,608</td>
<td>48,504</td>
<td>117,313</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Only four instead of five trap-nights due to a technical problem.*
roссicus followed by the snow-pool mosquitoes *Aedes intrudens* and *Aedes communis* (Table 1). Of the 14 species found, five were floodwater mosquitoes (*Aedes cinereus*, *Ae. rossicus*, *Aedes nigrinus*, *Ae. sticticus*, and *Ae. vexans*), six were snow-pool mosquitoes (*Aedes cantans*, *Aedes communis*, *Aedes dianaeus*, *Aedes excrucians*, *Aedes intrudens*, and *Aedes punctor*), and the rest were *Culex pipiens/torrentium* (FG 1d), *Caliseta bergrothi* (FG 1c), and *Culiseta morsitans* (FG 2e). The records of *Ae. vexans*, *Ae. sticticus*, *Ae. rossicus*, and *Ae. excrucians* are the first for the Swedish province of Norrbotten.

During the first sampling of the season at the end of June, the snow-pool mosquitoes occurred in large numbers and dominated the mosquito fauna at all four trap sites (Figure 2). However, from week 27 and onwards, the snow-pool mosquitoes diminished in numbers and the floodwater mosquitoes increased dramatically. Three of the study sites (Ekopark, Kuiva, and SJ) were completely dominated by floodwater mosquitoes in weeks 27 to 33. The snow-pool mosquitoes only remained as the dominating FG for the whole study period at Ruskola trap site.

Of the floodwater mosquitoes, *Aedes rossicus* was the most abundant species, representing 98% of all mosquitoes caught from this functional group and 51.9% of all caught mosquitoes (Table 1). The average abundance of *Aedes rossicus* over the full season was ~3,400 individuals (max: ~13,700) per CDC trap-night. The second most common species was *Ae. intrudens* (19.9% of total catch) followed by *Ae. communis* (19.0%) (Table 1). The highest numbers of *Aedes rossicus* were recorded during week 27 in Ekopark and SJ, with ~13,700 and ~13,500 specimens per trap-night, respectively. After the peak in week 27, the abundance of mosquitoes declined gradually from a mean of ~9,400 per trap-night in week 27, down to ~900 per trap-night in week 33 (Figure 3). Study site Ekopark had the highest percentage of *Ae. rossicus* during the season (64.6%), followed by SJ (60.4%), Kuiva (57.7%), and Ruskola (19.4%).

The annual water discharge pattern in the River Tornéälven varies tremendously, with a distinct peak in spring or early summer each year (Figure 4). The annual peak discharge in 2014 was 2,060 m$^3$/s (May 28), followed by a second peak with 1,880 m$^3$/s (June 14) (Figure 5). Based on the water discharge curve for 2014, we decided to consider 1,000 m$^3$/s or more as a signal of a flood situation in the River Tornéälven floodplain, implying that water will reach the temporary flooded meadows harboring the dormant egg bank of floodwater mosquitoes.

The daily average air temperature reached its maximum during the early summer on May 23 (16°C) and was followed by a second temperature peak on June 6 (20.5°C) (Figure 5). Average air temperature during the presumed larval period (mid-May to mid-June) was 11.3°C.

**DISCUSSION**

Our study showed that Övertorneå city had a substantial mosquito nuisance problem in 2014, and surprisingly, that the cause was *Ae. rossicus*, a floodwater mosquito. Previous reports on mosquitoes in the very north of Europe have concluded that species of snow-pool mosquitoes are dominating, for example in northern Sweden (Schäfer and Lundström 2001), northern Finland (Utrio 1979), and northern Norway (Mehl et al. 1983). This study is, to our knowledge, the first to identify a floodwater mosquito as the main cause of nuisance near the Arctic Circle, and the documented abundance of host-seeking female mosquitoes was very high, especially for being measured in a city. According to the Swedish environmental protection agency, 5,000 mosquitoes or more per trap-night is considered unbearable and sufficiently high to allow for larviciding with VectoBac G* by helicopter in Natura 2000 sites (Swedish EPA, act NV-07529-15, 2016-04-28). We recorded more than 5,000 *Ae. rossicus* per trap-night on five occasions, with a maximum of ~13,700 per trap-night. Previous sampling in Sweden have shown a generally low abundance of this species, except for the River Dalälven floodplains in central Sweden. The maximum number measured between 2001 and 2011 in the River Dalälven floodplains was ~8,100 *Ae. rossicus* per trap-night, obtained in 2010 when extensive flooding also occurred (Schäfer and Lundström, unpublished data). The number of *Ae. rossicus* per trap-night collected in this study is probably the highest recorded abundance of *Ae. rossicus* in the literature. Although mentioned as a pest species in several European countries, including Sweden (Becker and Ludwig 1983, Jalili and Halgos 2004, Jaenson 1986, Schäfer et al. 2008), it is usually not reported as the major nuisance species.

The massive occurrence of host-seeking female *Ae. rossicus* in the River Torneälven floodplain during 2014 began early in July. The population of *Ae. rossicus* started to decrease in the middle of July, and with no additional floods there was no further production of floodwater mosquitoes in 2014. Still, rather high numbers of mosquitoes were caught until the end of summer. We are aware of the difficulties with the balance between efforts and results, but we believe that the applied sampling strategy in this study gives a relatively good representation of the actual variation in mosquito abundances over the study period.

One study site, Ruskola, had fewer floodwater mosquitoes than the others, although only located at 2.8 km away from the other study sites. Ruskola was also located little further away from potential flooding areas compared to the other sites. This supports the idea that *Ae. rossicus* is not a long-distance flying mosquito species (Becker et al. 2010) and implies that the nuisance level in the city could have been even worse if a long-distance flying species such as *Ae. sticticus* had been the problem.

According to citizens in the area, mosquito nuisance has been even worse in previous years. The numbers of *Ae. rossicus* caught per trap-night in 2014 are relatively high, but considering the large fluctuations in river discharge over the years, the nuisance problems are likely to be recurrent. The flood that produced the mosquito nuisance in 2014 was not unique, and floods of similar magnitude and duration appear to occur annually in early summer, with a second flood occurring in some years.

The floodwater mosquito *Ae. rossicus* was first described in Sweden from the River Dalälven floodplain and was considered a rare species in Scandinavia that only occurred in a few locations in Sweden and Norway (Jaenson 1986). However, a recent compilation of the geographic occurrence of *Ae. rossicus* in Sweden shows that it has been found in almost the whole country but not as far north as Övertorneå city in the province of Norrbotten (Lundström et al. 2013). The present study reveals that it occurs in the very north of Sweden, and that it can be a major nuisance problem even as far north as the Arctic Circle.
Figure 2. Seasonal abundance of snow-pool mosquitoes (grey bars) and floodwater mosquitoes (black bars) in Övertorneå city, northern Sweden, during the summer of 2014 as measured with one CDC-trap per night and week during June (week 26) to August (week 33). a) Study site 1: Ruskola (5 trap-nights), b) Study site 2: Ekopark (4 trap-nights), c) Study site 3: Kuiva (4 trap-nights), d) Study site 4: SJ (5 trap-nights).

Figure 3. The weekly abundance of *Aedes rossicus* collected at four study sites in Övertorneå city, northern Sweden, during five sampling occasions during weeks 26-33 in the summer of 2014. The bar chart shows mean number (top of bar) and highest number (whisker) of mosquitoes. N/A means no trapping was conducted.
Figure 4. Seasonal and annual water discharge variation in the unregulated River Torneälven, northern Sweden, for the years 2011 to 2015. The daily water discharge was measured at the Kukkolankoski hydrologic station and provided by the Swedish Metrological and Hydrological Institute, Norrköping, Sweden (www.smhi.se).

Figure 5. The average daily temperatures and the daily river discharge in the floodplains of River Torneälven, northern Sweden, in May to August 2014. The temperature data is from the Ylienjärvi meteorological station, and the daily river discharge is from the Kukkolankoski hydrological station, and both provided by the Swedish Metrological and Hydrological Institute, Norrköping, Sweden (www.smhi.se).
High numbers of floodwater mosquitoes have been recorded before in several places in Sweden but never this far north. The Swedish area most affected by floodwater mosquito nuisance used to be the River Dalälven floodplains, but after more than a decade of mosquito control based on larviciding with VectoBac G, the abundance of floodwater mosquitoes has been reduced to below nuisance level (Schäfer and Lundström 2014). The main nuisance species in this area is *Ae. sticticus*, with measurements of up to 53,000 individuals per trap-night before full-scale mosquito control was introduced in the area (Schäfer and Lundström 2009).

In the present study, *Ae. sticticus* was found far north of its known distribution in southern and central Sweden (Lundström et al. 2013). Schäfer and Lundström (2009) showed that the species can be expected to expand its distribution northwards as the climate gets milder due to global warming. That we actually recorded *Ae. sticticus* in the City of Övertorneå suggests that it might be more tolerant to the climate in northern Sweden than earlier expected, or that the climate has changed sufficiently to allow establishment of the species (Schäfer and Lundström 2009). With sufficient high temperatures it may develop into a major nuisance also in the River Tornéälven floodplains.

*Aedes vexans* has been found in northern parts of Sweden in earlier studies (Dahl 1977, Lundström et al. 2013) and also in northern parts of North America (Wood et al. 1979, Triebenbach et al. 2010), but this was the first finding in Norrbotten, Sweden. We found them in low numbers, suggesting that the habitat and/or climate is not optimal. Another floodwater mosquito, *Aedes nigirinus*, was also recorded in this study. This species has only been found a few times in Sweden before, in the regions of Norrbotten, Halland, and Småland (Lundström et al. 2013). Altogether, five out of nine floodwater mosquitoes known to Sweden were found in this study. The four species not found (*Aedes dorsalis*, *Ae. caspius*, *Aedes geminus*, and *Ae. detritus*) are only known from the southern half of Sweden (Lundström et al. 2013), though *Ae. dorsalis* has been found in arctic regions before (Reeves et al. 2013).

Our study demonstrates that production of floodwater mosquitoes is a natural component of the floodplain fauna of rivers with a fluctuating water flow regime, and that floodwater mosquito nuisance is not restricted to southern and central Sweden but can occur as far north as the Arctic Circle. Surprisingly, the floodwater mosquito *Ae. rossicus* turned out to be the major species in this northern location, while *Ae. sticticus* is the most notorious floodwater mosquito species in Sweden in general. This raises the question concerning which factors may determine the dominance of certain species in certain areas.

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