Classification system of mosquito breeding sites for a dune and salt marsh complex

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Introduction

Mosquito nuisance events were recorded on the East Frisian Islands at least since 2004 (e.g. Baltrum: Wietjes, personal communication; Mellum: Sven Oltrop, personal communication). Our study was motivated by the fact that a limitation of tourism through plague events could endanger the economic basis of these islands, which is primarily based on about 10 million overnight stays a year (Niedersächsisches Ministerium für Wirtschaft, Arbeit und Verkehr 2005).

Scientific statements on mosquito control measurements and reliable predictions of future plagues were difficult, because basic data about the pest species and their breeding sites were scarce. This could be traced back to a significant reduction of scientific research on mosquitoes in Germany in the middle of the 20th century, which was closely linked to the eradication of malaria (Weyer 1956) through consequent dewatering and drainage of marshes, swamps and fens (Maier 2004). Additional factors were housing improvement, advances in hygiene, optimization of diagnostic methods, and effective treatment of malaria cases (Bruce Chwatt & Zulueta 1980).

This lack of information in particular matched the island chain. In a first step, the aim of this study was the identification of suitable and unsuitable water bodies by a small number of environmental data.

Material and methods

Study area

The East Frisian Islands are situated in the 278,000 ha Wadden Sea National Park of Lower Saxony. The climate within this region is maritime, semi-humid and moderately temperate (Bauer 1996) with the average temperature about 10 °C and the annual precipitation between 600 to 800 mm.

Having a total area of 7 km² (5 km in maximum length, 1.4 km in maximum width), Baltrum is the smallest of the permanently inhabited islands. The 63 ha area, where most of the studies were carried out, is situated in the most eastern part of Baltrum. Due to seasonal flooding by tidal saltwater, soil salinities here rise to about 5–20‰ (Scheffer & Schachtschabel 2002), thus causing the typical vegetation types of salt marshes and dunes (Pott 1995; Nationalparkverwaltung Niedersächsisches Wattenmeer 2004). Except for a few trails and drainage ditches, there is no anthropogenic use in this part of the island.
Fig. 1: Number of colonised permanent and temporary pools and ditches.

**Biotic & abiotic data**

Species composition, densities of larvae and pupae, and phenology of mosquitoes were studied for 47 pools and ditches approximately every two weeks (every 14-19 days) between March and July 2008. Immature stages were sampled with a 500 µm mesh net (frame height and width 250 mm). Furthermore, abiotic and biotic data were collected for every water body: duration of flooding (= occasions with water present), surface area, water depth, total cover of vegetation, maximal vegetation height, exposition to the wind, and pH, conductivity, salinity, oxygen (% and mg/l).

**Data analyses**

The software Canoco (Version 4.5, Biometrics©) was used to explore differences between the pools via Partial Correspondence Analysis (PCA). Density data were therefore log (n+1) transformed. Waters were grouped in categories based on PCA results and their data were compared with the Kruskal-Wallis test. All results were used to develop a simple classification key for potential mosquito breeding sites on the East Frisian Islands.

**Results**

Permanent pools and ditches or water bodies with direct connection to the North Sea were never colonised by mosquitoes (Fig. 1, Fig. 2). The first two dimensions of the PCA explained 84.6% of inertia (Fig. 3). According to the ordination diagram, two groups were identified. These mirrored a differentiation between pools that were colonised before drought (black circles), having a short duration of flooding (data not shown here), and pools that were only colonised after drought (black rectangles), which had a long duration of flooding (data not shown here). Mosquito density differed significantly between the groups (Kruskal-Wallis-Test, p<0.05) (Tab. 1), which also matched the abiotic data “duration of flooding”, “surface area”, and “water depth” (Kruskal-Wallis-Test, p<0.05). Not surprisingly, these parameters were correlated with each other (not shown here). Therefore, only the parameter “day of flooding” was used in dichotomy key. Other environmental data showed no significant differences (not shown here).
Discussion

Mosquitoes colonized only temporary pools and ditches (Fig. 1). This matched observations by Wilbur (1987), who assumed a predation avoiding strategy behind this kind of preference. Nevertheless, this is not necessarily the only factor, because also temporary pools are not ‘enemy-free’ (reviewed by Fryer 1986). Some common predators in temporary pools could be Notonecta, predatory Coleoptera or Odonata (Williams 1997).

Furthermore, waters with a connection to the North Sea were never colonised (Fig. 2), which could be the result of two environmental conditions: tidal velocity and predation. These habitats are probably unsuitable, because the mosquitoes would risk to become flushed out by the tides (Remmert 1955). Another reason again could be the effect of predators, e.g., Resh and Balling (1983) observed an improved fish species access to the aquatic system in marshes via tidal ditches.

The genus *Ochlerotatus* predominated all sampling dates before and after drought. The most native species of this genus are typical flood water mosquitoes and deposit their eggs into the soil in dried habitats (Pfeffer & Dobler 2008). In contrast, species of the genus *Culex* and *Anopheles* showed a preference for waters, which were not colonised before drought. These waters significantly differed from the other waters by higher surface area, water depth, and longer water duration (Tab. 1). Mosquitoes of this genera need a longer duration of flooding, because their eggs do not tolerate drought (e.g. Bradshaw and Holzapfel 1988).

Conclusion

Based on field data, we developed a dichotomy key for simple identification of mosquito breeding sites on the East Frisian Islands (Fig. 4). Prior ranking factors for the differentiation of suitable and unsuitable habitats were “connection to the North Sea” and “hydrology” (permanent/temporary). An additional factor was “duration of flooding”, which was usable for the containment of the colonisation time and a rough description of the mosquito genera composition.

Our approach appears to be a promising first step for the identification of mosquito breeding sites of the coastal areas in Northern Germany, and future research could focus on these pools and ditches. Nevertheless, we especially need more information on the transferability to other coastal areas. Further studies should focus on the relationship between mosquitoes and more detailed environ-
mental variables, e.g., spatial distribution of waters, vegetation, variability of hydrology, and predators.

Tab. 1: Significant results of the Kruskal-Wallis-test between the groups identified with PCA (Fig. 3).

<table>
<thead>
<tr>
<th>data</th>
<th>H-value</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>mosquito density</td>
<td>8.473</td>
<td>0.020</td>
</tr>
<tr>
<td>surface area</td>
<td>14.063</td>
<td>0.003</td>
</tr>
<tr>
<td>water depth</td>
<td>9.237</td>
<td>0.026</td>
</tr>
<tr>
<td>day of flooding</td>
<td>8.928</td>
<td>0.030</td>
</tr>
</tbody>
</table>

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Fig. 4: Dichotomy key for the identification of mosquito suitable waters on the East Frisian Island of Baltrum and information on the predominating genera.


