

Implementation of *Geographic Information System* (GIS) in an environment friendly mosquito control programme in irrigation fields in Wrocław (Poland)

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Abstract

GIS and remote sensing techniques are increasingly being used for modelling approaches to public health issues, especially when dealing with vector-borne diseases. They facilitate identification and mapping of the aquatic habitats of many mosquito species, and contribute to successful control operations. In this study the GIS database of mosquito breeding sites in irrigation fields in Wrocław, Poland, enabled analysis of the relevant biological parameters (larval emergence, abundance, development) of the various nuisance mosquitoes (Diptera: Culicidae) involved, and enhanced the efficacy and sustainability of the control programme. The ArcView software employed allowed preparation of a detailed map precisely delineating mosquito-breeding sites within these irrigation fields, using digital guidelines (polygons). Employment of GPS allows better accordance with features of the terrain and further increases accuracy. This map shows the exact locations of the mosquito-breeding sites, with calculated size based on their geometry. It enables more precise, better timed aerial applications to be made and above all, economies in use of microbial larvicidal agents. In addition to facilitating control of resident species, this system should make establishment of potential invasive pest or vector mosquitoes more difficult.

Key words: GIS database, GPS, microbial agents, mosquito control, irrigation fields, Wrocław, Poland

Introduction

More than a half of the world's population lives under constant risk of pathogens transmitted by mosquitoes (WHO, 2008). Malaria alone kills over 1 million people each year (3000 each day) and a minimum of 300 million people suffer from acute malaria, occasionally with lethal outcome (Trape *et al.*, 2002). It affects more than 100 tropical countries, placing 3.3 billion people (more than 40% of the world population) at risk (Becker *et al.*, 2010).

Increases in international travel and cross-border movements have contributed to the importation of malaria into western European countries (Becker, 2008). The potential vector capacity of European resident and invasive mosquito species appears to extend to both autochthonous and allochthonous viruses. In addition to endemic vector borne parasites, exotic pathogens are also introduced by migratory birds or infected travellers (Takken & Knols, 2007). Human and equine

West Nile fever outbreaks have been regularly reported from the countries of southern and central Europe for almost 50 years, with an increase in frequency and severity since 1994 (Hubálek & Halouzka, 1999). Arboviral diseases such as dengue, yellow fever (YF), West Nile (WN) and Chikungunya (CHICK) viruses originating from the African continent constantly pose risks of introduction or reintroduction (Bonilauri *et al.*, 2008).

Geographic Information Systems (GIS) are presently widely used by professionals in research, government and industry, in dealing with spatially related data (Kistemann *et al.*, 2002). With the use and analysis of data obtained by contemporary technology based on GIS and GPS (*Global Positioning System*), it is possible to get relevant data on the location and size of mosquito larval sites, estimate the density of insect populations, decide on insecticidal product to be used, and employ optimal techniques to create a rational, environmentally friendly strategy to control nuisance mosquitoes and vector-borne diseases (Zou *et al.*, 2006).

A Geographic Information System consists of an organized collection of computer hardware, software, and geographic data, designed to efficiently collect, store, update, analyze and display all forms of geographically referenced information (Kistemann *et al.*, 2002). Modern information technology allows the integration of GIS systems with database technology, and with digital mobile field data collection systems supported by a GPS. The ability to link information about where things are (location and geometry data), with the properties about what things are like (attribute data), provides the user with a better understanding of ecology and spatial phenomena, and with their relationships, which may not be apparent without such advanced techniques of query, selection, analysis and display.

Typical applications of GIS are:

- Mapping locations of certain features.
- Mapping quantities and densities of certain species.
- Determining properties of distinct areas using database queries.
- Mapping change by recording how features change over a period of time, in order to forecast future conditions.

GIS and information technology can greatly improve the survey, logistics and documentation of mosquito control operations (Becker *et al.*, 2010). Possible applications range from direct digital site mapping, using GPS assisted mobile devices, to timely aggregation of operational reports. A spatially referenced database containing all features of interest is the basis for all further data collection and analysis. This spatial element enables thematically related features (e.g. population densities of certain species, flooding areas, plant associations and vegetation type, locations of aggregations of nuisance mosquitoes or disease vectors) to be organized in separate layers of information, which can eventually be analyzed and displayed in a user-defined context.

To enhance the efficacy of control, organizing an outline of possible applications is presented as follows:

- Analysis of available digital maps (e.g. hydrology, flooding zones, wetland inventories), to determine potential larval habitats.
- Spatial analysis to determine relationships between nuisance or disease vector species, and their breeding sites (calculation of buffer-zones, map and database-query).
- GPS-assisted field data collection and breeding-site inspection (detailed habitat mapping, larval and pupal survey). The use of handheld systems that synchronize data with the main database, allows accurate and timely processing of results and of database updates.

- Forecasting time and location of appropriate control activities, based on correlations between the spatial occurrence of triggering events for larval development (e.g. water level fluctuations and flooding areas, local weather data, the potential of larval development sites, and the complete current survey data).
- Preparation of operational maps to improve logistics, calculate the quantities of control materials, manpower required and hence the duration and costs of treatment.
- Storage of historical-site profiles and related data on the basis of operational maps enables prediction of future potential larval development, resulting from dynamic triggering events, GPS-assisted operations allow the tracking and direct digital documentation of field activities (e.g. aerial application).
- Reports and documentation of survey and control activities can be assisted by user defined database and map queries, which give immediate access to information stored in the database.

Answers to queries can then be visualized and printed in the form of standardized thematic maps, graphics or tables.

Precise mapping and individual numbering of each significant breeding-site enables rapid and effective communication between field staff, which provides a solid basis for a successful larviciding operation (Becker *et al.*, 2010). Several other studies can be carried out during mapping: 1. assessment of the diversity and abundance of mosquito species in the control area; 2. characterization (type) of the breeding sites according to their productivity (number of mosquito larvae) and mosquito population dynamics; and 3. assessment of the ecological conditions in the major breeding sites, e.g. plant associations, occurrence of predators, or rare and sensitive organisms which indicate the frequency of flooding.

The main objective of this research was to generate a GIS database including all previously existing data about the irrigation field system in Wrocław (e.g. engineering infrastructure, soil classification) and the data collected during the field work (e.g. mosquito species composition and distribution within the study area, management of the flooding regime) using ArcView software. This database will be used to analyze relevant biological parameters (larval emergence, abundance, development) for controlling the nuisance mosquito species occurring in the irrigation fields.

Material and Methods

General description of the study area

Wrocław is situated on the Odra River and four tributaries, the Śleza, Bystrzyca, Widawa and Oawa (Rydzanicz *et al.*, 2010). This situation includes many floodplain areas, an extensive system of ditches and tributaries in and around of the city of Wrocław, hundreds of permanent natural and man-made habitats for mosquito breeding such as ponds, marshes, irrigation and drainage systems, sewage disposal sites, potholes, pools, wells, and other more or less transient collections of water in natural and artificial depressions. The number and diversity of mosquito-breeding sites have caused a long standing public demand for mosquito control and an environmentally friendly control programme has been in effect since 1998. Some breeding sites have been physically eliminated; some are seeded each year with indigenous fish species, whilst others are controlled with microbial agents, mostly *Bacillus thuringiensis israelensis*.

This study was made in the irrigation fields situated in the north-western part of Wrocław (Rydzanicz *et al.*, 2008). The irrigation fields were constructed in 1890 to provide natural sewage purification in a total area of 1000 ha. The sewage purification system consists of sewage reservoirs, sewage canals, ancient river meanders, meadow infiltration basins and underground drainage pipe systems (Rydzanicz *et al.*, 2009). Each day about c.60, 000 m³ of sewage is pumped into sewage farms belonging to various sewage reservoirs. The infiltration time depends on the vegetation period and soil conditions. After filtration in the meadows, the underground drainage system collects the purified water and empties into the Odra River. This area comprises the largest and the most important local mosquito source. Floodwater mosquitoes, mostly *Ochlerotatus caspius* [Pallas] and *Aedes vexans* [Meigen], emerge from these fields in huge numbers every summer during which there is intermittent flooding when wastewater enters the infiltration fields (meadows), causing a tremendous biting nuisance (Rydzanicz *et al.*, 2008). This area is also inhabited by about 180 bird species (migrant and resident), creating appropriate conditions for potential transmission of West Nile virus and other mosquito borne arboviruses.

Data collection

(a) Adult mosquito surveillance

The collection of adult mosquitoes was carried out in the irrigation fields from June to September 2008, using CO₂-baited CDC traps (Bioquip, USA) to attract host-seeking female mosquitoes. Depending on the mosquito density of the respective areas, up to 20 traps were set at about 1.5 m height within the vegetation for 2 nights/ each month. The mosquitoes captured were transported to the laboratory for species determination according to standard taxonomic keys to the mosquitoes of Europe (Becker *et al.*, 2010). Our studies so far have ascertained that three distinct *Culex* populations are present in the study area. *Culex pipiens* (Linnaeus) is represented by the anautogenous, strongly ornithophilic nominal biotype and the autogenous, markedly anthropophilic *molestus* (Forsk.) biotype. The third population is of the morphologically similar, ornithophilic *Culex torrentium* (Martini). As yet we have no information on relative densities. We do, however, have knowledge of comparative migration rates of floodwater aedine mosquitoes (c. 15 km/day) and the *Culex* species (c. 0.5 km/day) and implementation of buffer zone construction enabled modelling of potential mosquito distribution.

(b) Larval mosquito monitoring

Investigations on species composition of mosquito larvae, breeding-site preferences (in tandem with adult biting behaviour) were investigated during the “mosquito seasons” of 2007-2008. Mosquito larvae in all existing breeding sites were sampled using a WHO dipper. In each of 10 dips the numbers of larval stages L1-L2, L3-L4 and pupae were counted and recorded. A sufficient number of larvae were taken to the laboratory for rearing to the 4th instar or adult stages and detailed species identification after Becker *et al.* (2010).

(c) Mapping of mosquito-breeding sites

All existing situation maps, each to the scale 1:10,000, were used in the construction of an accurate database of mosquito aquatic sites in the Wrocław irrigation fields system. Additionally, all data relating to the engineering infrastructure and management of wastewater distribution, topography, soil classification, and potential vector distribution was examined and included. These data maps were then scanned and geo-referenced by use of Arc View 3.2 and Arc View 9.1 software.

All existing and potential breeding habitats in the study area were digitized and attributed manually as polygons. The CDC trap locations as well as selected mosquito-breeding sites were

recorded by using a GPS receiver (Garmin GPSmap® 60C Sx) and transferred to the database. It was then possible to provide graphical visualization of the mosquito-breeding sites as well as to identify specific zones with high larval abundance and to correlate them to the whole water body. This information enables communication between mosquito control organizers and the decision making processes (e.g. precise selection of localities and surface areas to be treated).

Results

The integration of maps showing the numbering system with those showing soil classification facilitates visualisation of ecological conditions and the extent of the mosquito problem. A total of 100 mosquito-breeding sites were located, mapped and characterized in 2007. As Figure 1 shows, the problem area encompasses a system of intermittently inundated fields in an area of mixed heavy-, middle-, light and sandy alluvial soils which, though allowing waste water filtration hold standing water for varying periods of time, The area has been divided into operational zones, each based on one of 12 sewage reservoirs. Each zone is sub-divided into sectors identified by a code number (sector number plus zone number, e.g. 35-01; 115-12), allowing easy identification of all habitats (Figure 1).

Mosquitoes breeding in the intermittent flooded meadows during this study consisted principally of three species, *Oc. caspius*, *Ae. vexans* and *Oc. cantans* [Meigen], but with the additional presence of *Oc. sticticus* [Meigen], *Oc. leucomelas* [Meigen] and a few individuals of the Anopheles Maculipennis Complex. Longer lasting, stagnant water in many meadows contained large populations of *Cx. pipiens* /*Cx. torrentium* and *Culiseta annulata* [Schrank]. Average numbers of mosquito larvae present in spring and summer, ranged from <1 to 40 specimens per 350 ml dipper. Vegetation in these meadows, with surface areas ranging from 0.57 to 15.81 ha and flooded to depths ranging from 0.1 to 0.7 m, consists mainly of species of *Gramineae*.

During the monitoring of the adult mosquitoes, a total of 59,648 adult specimens were collected in the CO₂ baited CDC light traps (Table 2). Species distribution and abundance varied between months, with *Oc. caspius* (54.7 %) followed by *Ae. vexans* (28.0 %) and *Cx. pipiens* /*Cx. torrentium* (17.3 %) accounting for the bulk of the total collected between June and September. However, as can be seen from the histograms in Figure 2, the number of *Cx. pipiens* /*Cx. torrentium* caught by these traps in July exceeded the combined catch of *Ae. vexans* and *Oc. caspius*.

Discussion

Recent developments clearly show that GIS has become an indispensable tool for processing, analyzing and visualizing spatial data within the domains of ecological research, disease ecology and environmental and public health concerns (Graham *et al.*, 2004; Kistemann *et al.*, 2002). GIS application allows users to create interactive queries, analyse spatial information, edit data and maps and is useful in definition of the habitats of nuisance as well as vector mosquito populations, which are influenced by environmental conditions. It not only enables creation of maps based on field monitoring but also allows production of forecasting maps for planning control strategies on small and large scales (Tourre *et al.*, 2008; Dongus *et al.*, 2009; Stensgaard *et al.*, 2009). Improved knowledge and progressive adoption of new technologies improve prospects for efficient pest control (Lonc *et al.*, 2004).

Improvements of definition, classification, and mapping of local mosquito developmental sites gained in the course of this study are expected to be of practical benefit to the mosquito control programme in Wrocław, which has operated in its present form since 1998. Better understanding

of species seasonal prevalence and distribution, of requirements of their aquatic developmental stages, of adult flight range, host choice, and life expectancy all contribute to informed choice of control methodology. Improvements of data analysis techniques offered by GIS programmes maximises the value of increased knowledge and allows better choice of single or combinations of available mosquito control strategies and larvicidal formulations.

Knowledge accumulated during the present work is helping in the development of improved strategy for larval control using microbial insecticides. Aerial application has already been done in certain areas of the irrigation fields to check the efficacy of *Bti* granules applied from helicopters (Rydzanicz *et al.*, 2010). Analysis of the accumulated data is contributing to the value our increasing knowledge of the seasonal dynamics of mosquito populations. Detailed and accurate mapping of aquatic sites, and employment of appropriate tools for achieving the required level of larval control, form a base for effective adult suppression. For example, recent laboratory studies have demonstrated that the variations of viability of overwintering eggs of *Oc. caspius* larvae depends on the quality of soil at the oviposition site, with higher hatching rates in eggs laid on middle alluvial soils (Rydzanicz *et al.*, 2010). This information should be taken into consideration during routine inspection of the breeding sites and when planning larval control by the precise use of microbial agents.

In contemporary mosquito control programmes it has been demonstrated that accurate mapping of breeding sites is of crucial importance in achieving acceptable results (Becker, 2009; Becker *et al.*, 2010). The characteristics of the site and application of environmentally friendly approaches to the control of mosquitoes would also lead to evaluation of different larvicidal formulations. Sound control includes employment of various methods, each more suited to particular programmes. However, appropriately targeted larvicidal treatments using advanced equipment and technology (i.e. GPS/GIS technology), are significantly more efficient than traditional methods of mosquito control. As was pointed out by Becker (2008), new strategies based on sound environmental approaches will be effective in vector control and in preventing potential risks of human diseases being transmitted by mosquitoes. Properly planned mosquito control projects based on cost effective strategies are more efficient, both from the cost and disease prevention standpoints.

The current phenomenon of global warming is well known (Becker, 2008). It is already apparent that, as a consequence of global climate change, we face changing distributions of indigenous nuisance mosquito species. Moreover, new records of tropical Asian mosquitoes, emergence of new diseases, or re-emergence of formerly endemic vector borne pathogens, are currently increasingly reported at higher latitudes, including the Netherlands and Germany (Scholte *et al.*, 2007, Pluskota *et al.*, 2008). We are witnessing changing ecological niches, which are becoming increasingly suitable for mosquitoes of medical and/or veterinary importance (Gratz, 2004). Databases may serve to predict potential future distributions of vector borne diseases following global climate change, and probabilities of the vectors being indigenous nuisance mosquitoes, or immigrant species presently occurring only at lower latitudes (Schäfer & Lundström, 2009).

Numerous studies have demonstrated benefits of using remote sensing and GIS in the identification of aquatic habitats of many vector mosquito species (Zou *et al.*, 2006, Caphina *et al.*, 2009). Realistically, the type of mosquito control strategy fitting in best with regional cultural and economic realities has the likelihood of consequent adoption. However, the strategy should be in accordance with needs and resources and, above all, with prevention of a mosquito nuisance and potential or actual transmission of vector-borne disease, and must use the most advantageous contemporary technology.

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Table 1. Characterisation of the selected mosquito-breeding sites occurring in the irrigation fields in Wrocław in 2007-2008.

| Month | Reservoir No. | Larval site No. | Area [ha] | Larvae (mean no.) | Sewage temp. [°C] | Depth [cm] | Mosquito species |
|-------|---------------|-----------------|-----------|-------------------|-------------------|------------|--|
| April | 07 | 121 | 2.52 | 4.22 | 15 | 40 | <i>Oc. cantans</i> |
| | 07 | 116 | 3.71 | 40.07 | 23 | 40 | <i>An. maculipennis s.l.</i> , <i>Ae. vexans</i> , <i>Oc. caspius</i> , <i>Cx. pipiens</i> <i>Cx. torrentium</i> , <i>Cs. annulata</i> |
| | 08 | 14a | 2.51 | 0.40 | 14 | 20 | <i>Oc. cantans</i> |
| | 08 | 146 | 0.75 | 0.54 | 10 | 50 | <i>Oc. cantans</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 09 | 8 | 3.24 | 0.77 | 10 | 30 | <i>Oc. cantans</i> , <i>Oc. leucomelas</i> |
| | 10 | 8 | 15.81 | 2.12 | 14 | 70 | <i>Oc. caspius</i> |
| | 10 | 84 | 5.10 | 8.67 | 17 | 30 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 12 | 85 | 2.04 | 0.17 | 11.5 | 40 | <i>Ae. vexans</i> , <i>Oc. cantans</i> |
| May | 02 | 79 | 1.93 | 39.60 | 16 | 20 | <i>Oc. caspius</i> |
| | 02 | 81 | 2.40 | 1.22 | 17 | 40 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 02 | 86 | 1.94 | 12.55 | 18 | 10 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 08 | 13 | 3.14 | 5.27 | 16.5 | 30 | <i>Ae. vexans</i> , <i>Oc. caspius</i> |
| | 08 | 98 | 1.79 | 34.90 | 17.5 | 40 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> , <i>Cs. annulata</i> |
| | 09 | 95 | 3.40 | 29.88 | 21 | 40 | <i>An. maculipennis s.l.</i> , <i>Ae. vexans</i> , <i>Oc. caspius</i> , <i>Cx. pipiens</i> <i>Cx. torrentium</i> , <i>Cs. annulata</i> |
| | 09 | 96 | 2.31 | 2.72 | 19 | 30 | <i>Ae. vexans</i> , <i>Oc. caspius</i> , <i>Oc. cantans</i> |
| | 09 | 97 | 2.50 | 10.22 | 19 | 40 | <i>Oc. Caspius</i> |
| June | 03 | 120 | 1.60 | 21.35 | 21 | 40 | <i>Cx. pipiens</i> <i>Cx. torrentium</i> |
| | 05 | 5 | 2.54 | 17.30 | 17.5 | 40 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 07 | 118 | 3.87 | 17.75 | 22 | 50 | <i>Oc. caspius</i> |
| | 07 | 120 | 3.19 | 21.35 | 21 | 50 | <i>Cx. pipiens</i> <i>Cx. torrentium</i> |
| | 07 | 122 | 5.56 | 27.92 | 17 | 40 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 08 | 104 | 2.87 | 42.67 | 24 | 30 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 08 | 107 | 2.31 | 11.95 | 22 | 20 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 08 | 108 | 1.83 | 24.10 | 21 | 40 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 08 | 109 | 1.31 | 7.57 | 22 | 40 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |
| | 08 | 112 | 2.56 | 10.5 | 20 | 40 | <i>Oc. caspius</i> , <i>Cx. Pipiens</i> <i>Cx. torrentium</i> |

| | | | | | | | |
|--------|----|-----|-------|-------|------|----|---|
| | 08 | 130 | 0.62 | 3.1 | 18 | 60 | <i>Oc. caspius, Cx. Pipiens</i> <i>l Cx. torrentium</i> |
| | 08 | 133 | 0.60 | 18.75 | 18 | 50 | <i>Oc. caspius, Cx. Pipiens</i> <i>l Cx. torrentium</i> |
| | 08 | 163 | 1.09 | 9.3 | 19 | 50 | <i>Oc. caspius, Cx. Pipiens</i> <i>l Cx.torrentium</i> |
| | 08 | 164 | 0.63 | 27.27 | 19.5 | 50 | <i>Oc. caspius, Cx. Pipiens</i> <i>l Cx.torrentium</i> |
| | 12 | 3 | 10.66 | 29.87 | 23 | 30 | <i>Oc. caspius, Cx. Pipiens</i> <i>l Cx. torrentium</i> |
| July | 04 | 141 | 4.14 | 61 | 19 | 40 | <i>Oc. caspius, Oc.</i> <i>sticticus, Cx. Pipiens l</i> <i>Cx. torrentium</i> |
| August | 08 | 124 | 0.57 | 6.5 | 17.5 | 40 | <i>Oc. caspius, Cx. Pipiens</i> <i>l Cx. torrentium</i> |
| | 10 | 27 | 5.39 | 1.65 | 20 | 50 | <i>Oc. caspius, Cx. Pipiens</i> <i>l Cx. torrentium</i> |

Table. 2. Total numbers of adult mosquitoes collected in the irrigated fields at Wrocław, 2008, showing percentage in each collection and relative frequency of the three commonest taxa.

| Mosquito collection | Percentage of season total | | | Total (%) |
|---|----------------------------|------|-----------|--------------|
| | June | July | September | |
| All adult specimens | 30.4 | 19.4 | 50.2 | 59,648 (100) |
| <i>Ae. vexans</i> | 6.7 | 4.5 | 16.8 | 703 (28.0) |
| <i>Oc. caspius</i> | 20.4 | 4.5 | 29.8 | 1373 (54.7) |
| <i>Cx. pipiens l</i> <i>Cx. torrentium</i> | 3.3 | 10.3 | 3.6 | 434 (17.3) |

Figure. 1. The number system of existing and potential mosquito-breeding sites and associated soil conditions in the irrigation fields in Wrocław.

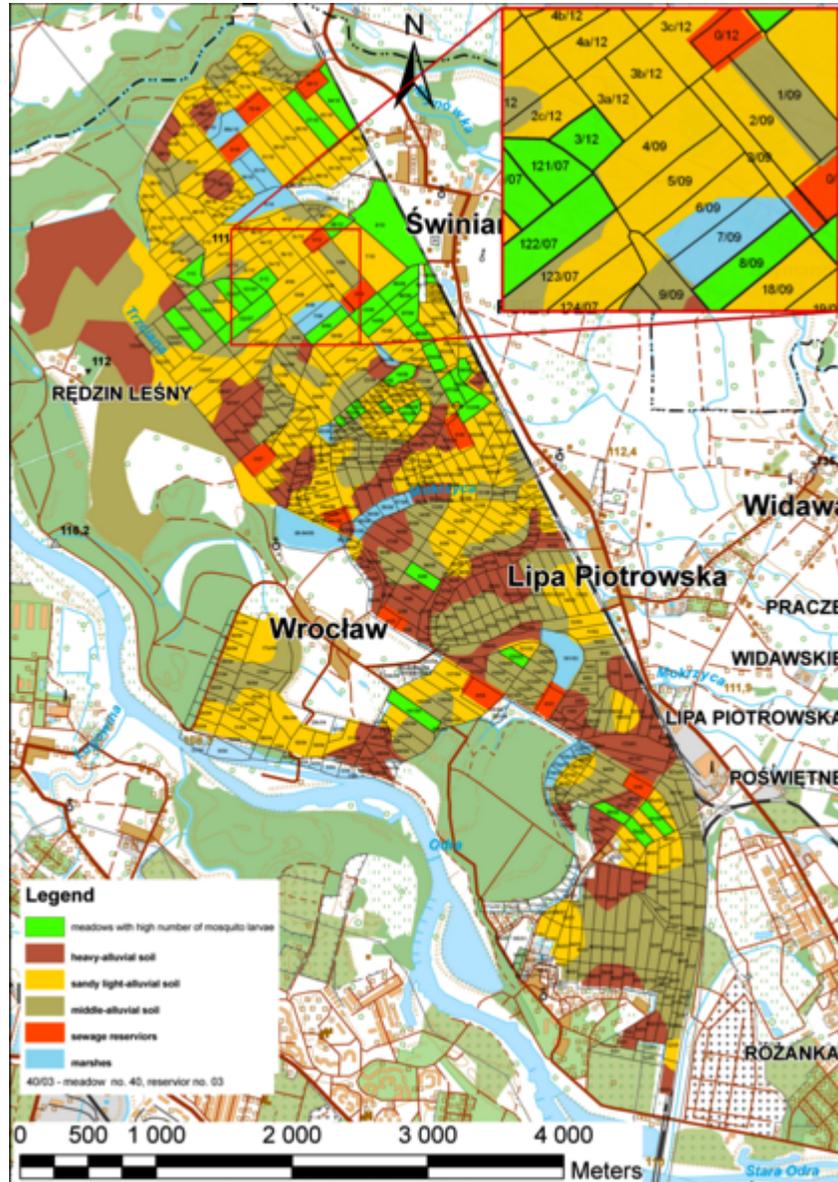


Figure 2. Adult mosquito occurrence in the irrigation fields in Wrocław from June to September 2008 and the possible distribution of the floodwater mosquito species.

