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Geoparticipation as a tool for mapping calamities mosquito hotspots: A case study from Litovelské Pomoraví, Czechia

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ABSTRACT

The coexistence of humans and nature has been a recurring theme throughout history, gaining particular importance in the context of climate change and the sustainability of our planet for future generations. However, the delicate balance between humans and nature is often disrupted, as exemplified by the Litovelské Pomoraví Protected Landscape Area in Czechia, where close interaction between humans and mosquitoes is a persistent issue. In this area, when environmental conditions are favorable for mosquito outbreaks, the local population living near the floodplain forests experiences significant discomfort for extended periods. The risk of mosquito overpopulation has intensified in recent years, largely attributed to climate change. Rising water temperatures in breeding habitats accelerate the developmental cycles of certain mosquito species, shortening the time required for maturation. This study aims to utilize modern geoinformation techniques to assess mosquito activity within the Litovelské Pomoraví region and evaluate the perceived impact on human populations. The methodological approach integrates the development of a representative population distribution layer and participatory mapping. These efforts culminate in the identification of active mosquito zones and the quantification of the at-risk population. While long-term data indicate that the situation is not deteriorating significantly, the study confirms that elevated mosquito activity continues to disrupt the daily lives of residents and visitors. Notably, summer mosquito outbreaks exert a broader impact than spring outbreaks, affecting both a larger geographic area and a greater proportion of the population.

The study's primary output, the spatial delineation of active mosquito zones and the identification of continuously populated areas at risk, holds significant value for the integrated management of the region. These findings can help mitigate the annual occurrence of mosquito outbreaks, improve the health of the floodplain forest ecosystem, and promote biodiversity conservation.

1. Introduction

The magnitude of mosquitoes' role in human life is undisputed — it has been some 100 years since mosquitoes were recognized and incriminated as playing a highly significant part in human affairs (Becker et al., 2010). Mosquitoes (*Culicidae*) are most frequently mentioned in relation to humans because of the diseases they transmit (see e.g. Dworrak and Kiel, 2023; Franklinos et al., 2019; Strelková and Halgoš, 2012), as well as their bites and buzzing (Elbers et al., 2015; Halasa et al., 2014).

Diseases transmitted by arthropod vectors are major contributors to the global burden of infectious disease (World Health Organization, 2017), with nearly half the world's population at threat of infection with a vector-borne pathogen at any moment (World Health Organization, 2014). Mosquitoes represent one of the largest groups of these vectors (Arnoldi et al., 2022; Eritja et al., 2005; Jansen et al., 2021). Their tremendous capacity to transmit infectious and potentially deadly pathogens and parasites makes them the most crucial blood-feeding arthropods worldwide. Malaria (around 212 million cases per year) or dengue (around 96 million cases per year) affect humans and can cause severe diseases or even lethal outcomes (Kilpatrick and Randolph, 2012; World Health Organization, 2017). Chikungunya and Zika virus disease both with 500–700 thousand cases per year are also frequent (Franklinos et al., 2019). In Central Europe, Batai virus, Sindbis virus, Tahyna virus, Usutu virus and West Nile virus could also affect humans (Camp et al., 2021; Holicki et al., 2020; Scheuch et al., 2018). The major driver of

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mosquito vector dispersal is the movement of people and goods. Most of the invasive species were introduced in Europe by international trade of used tires that can be used by mosquito as oviposition site (Giunti et al., 2023). The global use of freight containers to move goods from long distances has, thus, improved the chance of introducing insect species to non-native regions (Becker, 2008; Medlock et al., 2015). The frequency of intercontinental travel and trade and global warming allow foreign species to establish themselves in new environments where their natural enemies are not found (Strelková and Halgoš, 2012). Similarly, anthropogenic changes, such as climate change, urbanization, and environmental pollution, can affect their distribution (Cuthbert et al., 2023; Giunti et al., 2023; Wilke et al., 2021). For example, rising temperatures are creating the conditions for the spread of diseases previously common only in warmer climates. Tropical mosquito-borne diseases have rapidly become a threat to European public health that is proving difficult to confront (Calzolari, 2016; Semenza and Paz, 2021).

Besides these threats to public health, the **biting** and **host-seeking behaviors of mosquitoes** negatively affect humans (Halasa et al., 2014; Hubálek et al., 2010). Large numbers of blood-seeking female mosquitoes can cause a significant nuisance for humans by buzzing sounds or bites that cause itching (Verdonschot and Besse-Lototskaya, 2014). However, the target group includes not only humans but also game animals; for example, a permanently stressed deer may even die of exhaustion (Hubálek et al., 1998; Málková et al., 1974). Mosquito species might be valued as a nuisance when they are present in high densities (Blomgren et al., 2018; Burkett-Cadena et al., 2013), have more than one biting activity per day (Muhammad et al., 2020) and can fly distances over 2 km (Verdonschot and Besse-Lototskaya, 2014). In addition, adult mosquitoes need suitable resting sites and nectar sources in their vicinity, to be able to shelter from adverse weather conditions and predation, and to replenish their energy reserves (Elbers et al., 2015). Tolerance thresholds for the public's perceived nuisance can vary between mosquito species-specific biting and host-seeking behaviors (Dworrak and Kiel, 2023). When mosquitoes disperse into residential areas, mosquito nuisance could affect outdoor activities of the public and lower life quality (Brown et al., 2021; Halasa et al., 2014).

Breeding grounds as well as mosquito dispersal are species-specific (Becker et al., 2020; Verdonschot and Besse-Lototskaya, 2014). Abundance of these sites strongly influence the distance that individual adult female mosquitoes need to fly to lay their eggs (Elbers et al., 2015). The availability and distribution of blood hosts is also an important determinant of the daily **flight range** of mosquitoes (Bailey et al., 1965; Elbers et al., 2015). Some mosquitoes are poor fliers, while others can fly longer distances (Becker et al., 2010). These typical niches can be linked with landscape type – weak fliers are often found in urban domestic and in-forest environments, weak to moderate flyers occur in woodlands, and strong fliers can be found in more open areas (Verdonschot and Besse-Lototskaya, 2014). As stated in Elbers et al. (2015), the dispersal of adult mosquitoes can be generally classified into long-range and short-range dispersal (see Service, 1980, 1997). Long-range dispersal is often unintentional, aided by wind (i.e. strong winds that carry swarms of mosquitoes downwind) or human transport (transporting goods and passenger flights), and the distances between origin and destination can be up to hundreds of kilometers apart. On the other hand, short-range dispersal is often intentional. A further distinction can be made between non-oriented and oriented flight towards host location and attraction (Service, 1997) and are mediated by host-derived cues, such as odors (lactic acid, ammonia, fatty acids, CO_2), as well as humidity and body heat (Sutcliffe, 2010; Takken, 1996). This dispersal eventually results in a blood meal (Elbers et al., 2015). Non-oriented flights aim to increase the likelihood of encountering a host – species-dependent but also strongly influenced by the environment and thus sensitive to environmental change. Temperature, humidity, illumination, wind and local topography are key environmental determinants of non-oriented short-range dispersal. For example, drastic reductions in mosquito catches have been observed when the temperature dropped below 16 °C (Bidlingmayer, 1964). Moonlit nights have a positive effect on mosquito activity, probably because the light intensity of the full moon is close to the level at twilight (Bidlingmayer, 1964; Kampango et al., 2011). Intrinsic drivers of non-oriented flight include the mosquito's physiological status, such as egg maturation, mating status and energy balance (Klassen and Hocking, 1964). As for mosquito flight distances, average distances are comparable among mosquito genera, with recorded average maximum distances of 3 km for *Aedes*, 3.5 km for *Anopheles*, 5 km for *Culex* and 7.6 km for *Ochlerotatus* (Verdonschot and Besse-Lototskaya, 2014). Nevertheless, there are large variations within these genera. Some species, such as *Aedes polynesiensis*, *Aedes scutellaris*, and *Ochlerotatus rusticus*, have a very limited dispersal capacity of 50–100 m. In contrast, others are known for their strong dispersal abilities, including *Ochlerotatus taeniorhynchus* (32 km), *Anopheles freeborni* (35 km), *Aedes cantator* (48 km), and *Aedes sollicitans* (48 km; see in detail Verdonschot and Besse-Lototskaya, 2014).

Climate (and weather) affects not only the transmission of infectious diseases but also **mosquitoes' biological processes**. Dipteran vectors such as mosquitoes usually have a short life cycle, with full development from egg to hatch through four larval instars, pupation and then emergence as adults taking one week to months and development of each stage within days (de Souza and Weaver, 2024). Each female mosquito can lay 100 to 250 eggs in each clutch. Mosquito eggs can be broadly categorized into rapid-hatch eggs and delayed-hatch eggs (Hawkes and Hopkins, 2021). Rapid-hatch eggs are deposited directly on or near the water's surface and hatch within a few days. In contrast, delayed-hatch eggs are usually laid near water or on moist soil or vegetation some distance away. These eggs can endure for extended periods (months or even years) due to their resistance to drying out and ability to withstand extreme temperatures, including freezing winters. Dale and Knight (2008) specify that the timeframe for a complete cycle may be as short as five days in tropical and subtropical environments, and there are differences between species in terms of their development times. Climate change and the associated temperature rise may result in a significant shortening of the development cycle. This is confirmed by de Souza and Weaver (2024) when they mention temperature, humidity and precipitation affect fecundity, reproduction and inter-stadial developmental rates of the vector. Vector activity, biting rate and transmission probability all respond to temperature variations, whereas temperature also has an impact on the development between stages, according to them. All mosquitoes have an intimate relationship with wetlands, and water is an essential requirement for the larval stages (Dale and Knight, 2008). Changes in the hydrological regime and water and air temperatures are the key factors influencing mosquito species' composition, abundance, and ecology (Strelková and Halgoš, 2012). Intense precipitation may create more suitable aquatic environments for oviposition, larval development and survival of some vectors owing to the formation of stagnant water pools, the high humidity and surface moisture (de Souza and Weaver, 2024).

Recently, spring and summer in central Europe have been characterized by significant air temperature fluctuations. Precipitation has been irregularly spread during the year, in contrast with normal conditions featuring long dry periods alternating with heavy rains, which caused localized or extensive floods with mosquito calamities (Olejníček et al., 2003). **Changes in climatic conditions** lead to changes in the phenology of mosquitoes. Some mosquito species have reproductive cycles strongly associated with flooding (often called floodwater mosquitoes), such as *Aedes vexans* and *Aedes ochraceus* (de Souza and Weaver, 2024). Schäfer and Lundström (2014) also mentions *Aedes sticticticus* species. Floodwater mosquitoes lay their eggs, which can remain viable for many years, individually on moist soil above the water line to await flooding, leading to explosive populations following heavy rainfall or tidal flooding (Diniz et al., 2017). Strong winds associated with flooding storms may kill many adult mosquitoes if safe resting locations are not abundant (de Souza and Weaver, 2024). Floodwater mosquitoes then pose an immense nuisance to the local population living near these wetlands (Becker, 2006; M. L. Schäfer and Lundström, 2014). In Czechia, mosquito calamities frequent in the floodplains of the Morava River with various types of stagnant waters, which offer suitable conditions for mosquito breeding – and are documented mainly through studies related to the lower course of the river, in South Moravia region (see e.g. Berec et al., 2014; Minář et al., 2001; Olejníček et al., 2003; Palička, 1967; Šebesta et al., 2012). The water regime of the floodplain forests of Moravia is very favorable for the regular and often mass occurrence of various mosquito species. The best conditions for larval development are provided by the floodplain forests for mosquitoes of the genera *Aedes* and *Ochlerotatus* (Strelková and Halgoš, 2012), which are decisive contributors to **mosquito calamities**. Calamity states are defined by the number of stings per minute in populated areas. For instance, in the Czechia, a calamitous occurrence is a situation where ten or more attacks per minute are recorded in the built-up area of a municipality outside the time of peak activity (Šebesta et al., 2012). Hygienists consider this value to be the limit of an acceptable load, and exceeding it poses a significant threat of harm to human health. Spring calamities are most often caused by early or late spring species that are univoltine (monovoltine), i.e. they produce only one generation per year. These include *Ochlerotatus cantants*, *Oc. communis* and *Oc. cataphylla* (Alekseev et al., 2007). Earlier snow melt and spring precipitation could result in a shift in the larval development of the spring univoltine species (Minář et al., 2007). Summer calamities are caused by summer species, which are multivoltine – they can produce more than one generation per year, but most often two or three. These are the late spring and summer species *Ochlerotatus sticticticus*, *Aedes vexans* and *Aedes cinereus* (Alekseev et al., 2007). The designation of spring or summer mosquito species should be understood as the period of their most frequent breeding, not as the period of actual adult emergence, which may be longer. The length of the developmental phase of mosquitoes varies considerably between spring and summer species. The period of inundation of the area, which allows their development, and the water temperature play a key role. Temperature determines the rate of larval development. Eggs can hatch shortly after flooding if the water temperature exceeds 9 °C. Temperature determines the rate of larval development, a process that can be as rapid as 1 week at 30 °C and up to 3 weeks at 15 °C (Vaux et al., 2021). Larval development can be rapid in temporary water bodies that remain wet from just a few days to several weeks, such as flooded meadows and low-lying areas with willow and reed (Becker et al., 2010). Eggs can survive up to 5 years if no flooding occurs after oviposition, with eggs normally spending the colder months – September to March – in diapause (Vaux et al., 2021). When flooding, eggs hatch in response to oxygen depletion, and not all hatch synchronously. The species adopt instalment hatching to maximise the survival of the populations should aquatic habitats dry out before adult emergence. Where conditions support development, huge larvae can be found with hundreds per litre and more than 100 million per hectare (Becker et al., 2010), the subsequent emergence of adult mosquitoes reaching biblical proportions. This mass emergence creates pressure for seeking blood meals, and females may be forced to migrate up to 15 km from their breeding grounds, with these founder sites leading to significant migration to other potential habitats (Petrić et al., 1999) and deter all normal human activities.

Reducing the threat of mosquito problems is then most effectively done at the larval stages when the larvae are spatially concentrated (Dale and Knight, 2008). It should be noted that the larvae are not a problem for humans, but it is important to prevent the adults from hatching and spreading into the surrounding area. Therefore, control by larvicides is based on source reduction of possible adults. Recently, efforts to drastically eradicate mosquitoes, that could lead to irreversible damage to the environment (nature), have been retreating. Some shifts are already evident in the study by Dale and Hulsman (1990), which, in the salt marsh context, have adopted a more benign approach, seeking to alter the environment minimally. They believe that relatively subtle changes can affect mosquitoes without destroying wetland function. In support of this, Mokany (2007) and Schäfer (2004) mentioned that mosquitoes abundant in ephemeral wetlands can significantly affect ecosystem processes and functions and, thus, the wetland value. Moreover, once emerged as adults, mosquitoes transfer huge volumes of biomass into the terrestrial food web, in turn contributing to the diets of insectivorous mammals, birds and other invertebrates (Hawkes and Hopkins, 2021). Mosquitoes belong to the group of bioindicators (Chowdhury et al., 2023), i.e. organisms used to monitor certain characteristics that help assess the degree of environmental changes occurring in an ecosystem (Alencar et al., 2021; Jardine et al., 2008). Bioindicators of such changes may include shifts in density or the disappearance of certain species (Chaves et al., 2016).

Mosquitoes, in relation to the ecosystem, perform a useful function and increase the value of the environment. Conversely, mosquitoes in high concentrations reduce the quality of life of the population living in close contact with nature. The solution is integrated territory management, considering both the environmental and social aspects – which should be evenly balanced. However, to intervene responsibly, it is first necessary to map the current situation in the area. Surveillance is essential to any integrated mosquito management program designed for native and non-native mosquitoes in natural, protected areas or urban settings (Martinou et al., 2020; Osório et al., 2014). Understanding mosquitoes' distribution, abundance and seasonality at the local scale is necessary for any risk assessment to be possible (Schaffner et al., 2013). Knowledge of the presence and current range of mosquito species occurrence in a given area is crucial to assessing the potential threat to human and animal health (Jawień et al., 2024; Strelková and Halgoš, 2012). Typically, mosquito surveillance is conducted by trained professionals, including medical entomology experts, public health officials, and researchers. This process demands substantial expertise and resources, encompassing personnel, equipment, and time (Martinou et al., 2020). The public can also contribute towards recording mosquitoes through citizen or community science projects where non-experts get involved in scientific research (Pataki et al., 2021). **Citizen science** can enhance and facilitate mosquito surveillance undertaken by authorities at the local level, ensuring better geographic coverage at a finer scale and providing essential information on mosquito diversity, distribution and habitat preferences (Braz Sousa et al., 2020; Palmer et al., 2017; Pernat et al., 2021). Citizen scientists, guided by experts and provided with mosquito identification keys, can contribute to mosquito recording by either collecting and submitting mosquito specimens to the experts or using mobile application technologies (Martinou et al., 2021). The active involvement of citizen scientists can enable data collection and overcome accessibility or transboundary limitations due to political or financial reasons (Pernat et al., 2021). Citizen science projects can contribute towards early warning rapid response systems by informing the authorities and the public. For this purpose, it is advisable to use geoparticipation tools, which involve local people who know the conditions and situation in the area in mapping mosquito activity.

Citizen engagement in decision-making through geoparticipatory spatial tools is one of the new research streams in socio-economic geography, behavioral geography, geoinformatics, political science and many other fields. In the last decade, participatory mapping methods or geoparticipatory tools have gained popularity among citizens and local government representatives who interact with citizens through digital technologies (Kahila-Tani et al., 2019; Mukherjee, 2015).

The concept of **geoparticipation** can be understood as usage of spatial tools to engage citizens in decision-making processes that affect them (Pánek, 2016). Most often, this involves making decisions about a public space, but it can also involve sharing information or perceptions about the environment in which they live. Although there is not yet a universally accepted definition, it can be understood as an umbrella term for technologies and approaches that enable citizens to engage in decision-making through map-based applications – whether analogue or digital. This decision-making often takes place regarding activities located in public space. Geoparticipation refers to using methodologies and tools that facilitate citizen engagement in decision-making processes related to spatial planning and resource management. This approach prioritizes the empowerment of communities by incorporating their local knowledge into formalized planning frameworks, thereby enhancing the inclusivity and effectiveness of governance practices. However, with the development of information technology, web-based and often mobile applications oriented towards collecting subjective and objective spatial information are increasingly coming to the fore (Falco and Kleinhans, 2018). It is worth mentioning, for example Bästa Platsen (Sweden), Carticipe-Debatomap (France), Commonplace (United Kingdom), CoUrbanize (USA), Social Pinpoint (Australia), Pocitové mapy (Czechia; in English as Emotional maps). These applications can be used for one-off data collection (e.g. creating a transport strategy or revitalising a housing estate) and for longer-term communication and information exchange between city/municipal authorities or researchers on the one hand and citizens on the other. Geoparticipation often employs participatory GIS (PGIS) techniques, which combine traditional GIS with participatory approaches. This includes using analogue (sketch maps) and digital (online platforms) environments. The primary benefits of geoparticipation include enhanced civic engagement, as it promotes broader citizen involvement in local governance processes. It also leads to improved decision-making by incorporating diverse perspectives, resulting in more informed and comprehensive policy development. Furthermore, geoparticipation fosters community empowerment by providing local groups (with local spatial knowledge) with tools to express their concerns and actively influence decision-making outcomes.

2. Objectives

A particular example of geoparticipation using modern geoinformation methods is the participatory mapping and assessment of mosquito activity conducted in 2023. This initiative is part of the methodology of integrated management of the area to minimize annually recurring calamitous mosquito populations with regard to improving the condition of the floodplain forest ecosystem while maintaining and strengthening biodiversity in the Litovelské Pomoraví Protected Landscape Area (from now on referred to as “Litovelské Pomoraví PLA” or just “PLA”).

This protected landscape area is located in north-central Moravia. It is situated along the Morava River. The local abundant water and wetland ecosystems are ideal breeding grounds for mosquitoes. The characteristics of this area are very close to those of the areas on the lower Morava River described in the studies mentioned in the Introduction chapter. When nature provides suitable conditions for developing their larvae, mosquito calamities afflict residents living in contact with the floodplain landscape for many weeks. As explained above, the threat of mosquito overpopulation has been exacerbated in recent years by climate change (Dale and Knight, 2008) – as water temperatures in the mosquito breeding grounds could rise quickly, the time required for the development cycle of mosquito species is shortened. At the same time, unpredictable weather patterns and flash floods occur more often.

Besides presenting a new, innovative, and universally applicable method of mapping mosquito calamity hotspots, the authors also provide a view of the current situation in the middle course of the Morava River. Related studies – either in terms of spatial delineation or simple assessment of activity during mosquito calamities – have not adequately addressed this area. The study on mapping of calamitous mosquito hotspots, which is the subject of this paper, is based on the following objectives:

A) to investigate the impact of this activity on humans;
B) to assess mosquito activity in a specific research area in the long term;
C) to spatially delineate the active zones;
D) to identify the affected population and define its spatial extent.

In the context of these objectives, the following two additional hypotheses were formulated:

I. Mosquito activity is worsening in a specific research area.
II. Summer mosquito calamities are more severe than spring calamities and have a greater impact on the humans.

The following three groups of respondents represent the target group of the study:

- residents permanently living in the specific research area;
- owners or users of secondary housing in the specific research area (cottage, cottage);
- visitors-tourists who visit the specific research area on a short-term and infrequent basis.

3. Data and processing procedure

For the study on mapping calamitous mosquito hotspots, a specific research area (see map in Fig. 1) was defined, which consists of the territory of all 22 municipalities through which the Litovelské Pomoraví PLA traverses. The specific research area covers an area of 465 sq. km (including 93.30 sq. km of the PLA).

The fulfilment of the defined research objectives A–D was carried out through the following three segments:

- Design and creation of representative population distribution data layers,
- Design and development of the questionnaire survey,
- Identification of active zones and quantification of the affected human population.

In a comprehensive form, it can be described as the first two segments of data acquisition and processing that enter into an overarching framework that deals with their integration and evaluation.

3.1. Representative population distribution data layers

The initial prerequisite for implementing the above research objectives is to have information on the distribution of the population in the specific research area. Traditional data sources (such as national registers) and their products capturing population distribution in space provide only a static view linked to the population’s residence or workplace, which is inaccurate and can be highly misleading. An example of a weakness is the common consideration of a person’s permanent residence, which may not sufficiently reflect the actual situation – in practice, it is common for a person to live in a different place than the one where they are registered for permanent residence. At the same time, a faithful description of the population distribution cannot be based on just one data source. It follows that the product of one layer (capturing only partial population state) is insufficient to describe the distribution; it must be the product of several variants.

This paper followed the methodology of Rypl and Burian (2023), which describes in detail the aggregation of several data sources (Czech national registers) to create a population grid in two basic variants – daily and night. So, it assumes that the distribution of the population varies between day and night, as well as on weekdays and weekends. The nature of the study does not allow data aggregation into administrative units (cadastral areas of municipalities or parts thereof), as is often the case. On the contrary, this would significantly reduce the data’s positional accuracy, making any investigation of spatial differentiation more difficult. Therefore, a grid (a regular grid through which a specific study area is divided into cells of the same shape and size) was used to allow the absolute population values to be relativized to the area

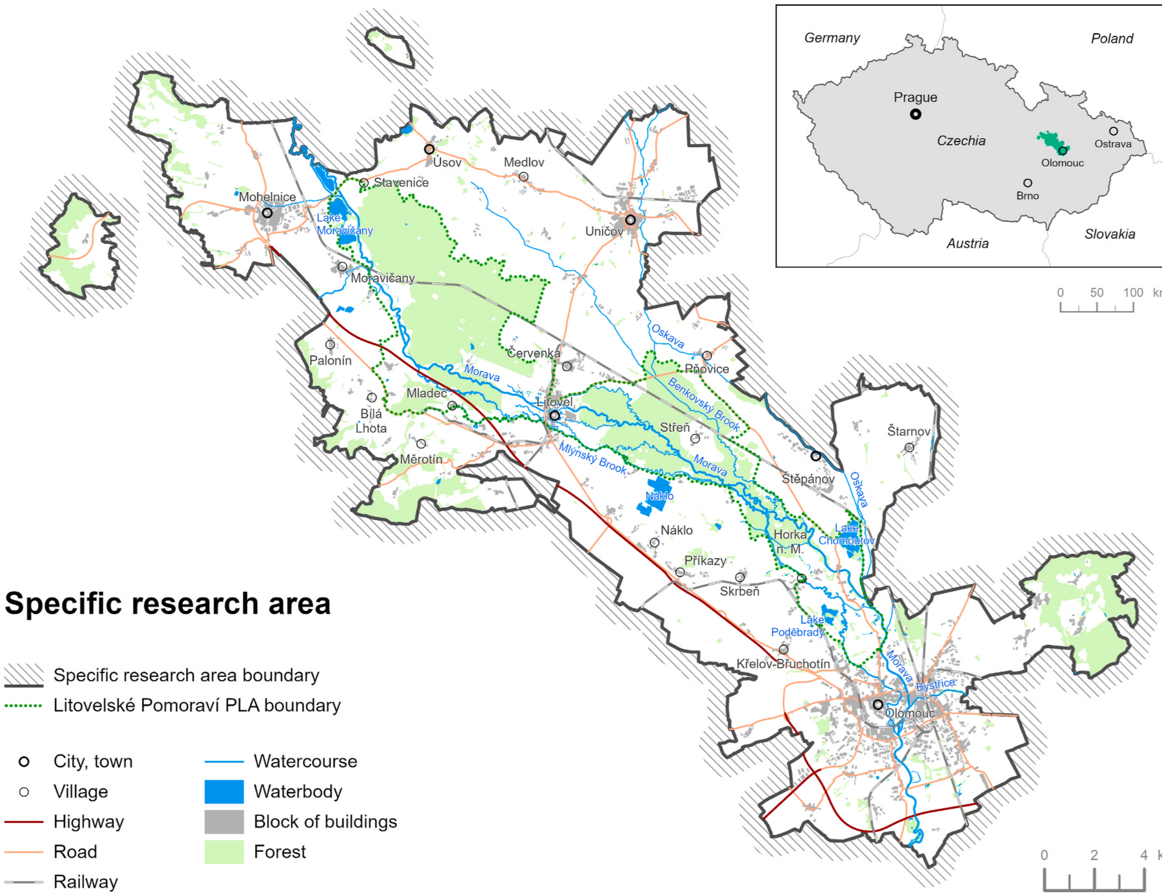

Fig. 1. Location and definition of the specific research area.

and maintain the necessary level of positional accuracy The procedure is described as a set of methodological steps linked to technical implementation in a GIS environment (ArcGIS Pro software). In the relevant part of the processing procedure, individual geospatial operations are indicated in brackets and italics.

Table 1
Overview of input data used for creating population distribution data layers – adapted from Rypl and Burian (2023).

	Input dataset (Data layer)	Level of detail	Year	Provider (*Source*)
1	Population	Address point	2021	Czech Statistical Office (*Population Census*)
2	Number of economically inactive and unemployed		2021	Czech Statistical Office (*Population Census, Register of Enumeration Districts and Buildings*)
3	Number of workers, employees		2022	Czech Statistical Office (*Register of Economic Entities*)
4	Number of children, students Number of teachers and school staff		2022	Regional Authority of the Olomouc Region, Czech Statistical Office (*Register of Enumeration Districts and Buildings*)
5	Number of seniors/retirees		2022	Ministry of Labor and Social Affairs of the Czech Republic *(Register of Social Service Provider)*
6	Specific research area	Group of municipalities (own delimitation)	2022	State Administration of Land Surveying and Cadaster (*Registry of Territorial Identification, Addresses and Real Estates*)

As can be seen from Table 1, six supporting datasets were used for aggregation when creating the population grid. Most are carrier datasets with information about the population (1–5) and one set representing the specific research area (6). These are mainly data from the Czech Statistical Office (Population Census, Register of Economic Entities), data from the registers of the Regional Authority of the Olomouc Region and the Ministry of Labor and Social Affairs of the Czech Republic (Register of Social Service Providers).

The night population state, which assumes the presence of the population in their homes, is based on the simple number of usual residents (Data layer 1; see Table 1). After creating a regular grid with a spatial resolution of 100 m × 100 m (*Create Fishnet* tool in ArcGIS Pro), the point records of the Population layer were aggregated at the level of each grid cell (*Summarize Within*). Subsequently, the vector output of the aggregated data was converted to a raster (*Feature to Raster*).

On the other hand, the daily state is more complex – it combines the numbers of economically inactive and unemployed, the numbers of workers and employees, the numbers of children, pupils and students, teachers and school staff, and the number of seniors (Data layers 2–5). As in the previous case, the initial step was to generate a regular grid with a spatial resolution of 100 m × 100 m for the specific research area (*Create Fishnet*; Data layer 6). Then, sub-aggregations of Data layers 2–5 were performed, summing the corresponding point records for each layer at the grid cell level *(Summarize Within*). These aggregates were then combined (*Union*) and summed again (*Calculate Field* with activated *sum* function) to produce the final aggregated layer in vector form, which was converted to a raster (*Feature to Raster* tool in ArcGIS Pro). These daily and night population states are relative to the working day. Capturing the population's behavior at the weekend, including the prediction of their concentration, is difficult to implement, as it depends on individual behavior and the specificities of the territory concerned, which are difficult to measure.

The aggregation procedure is explained in detail in the methodology of Rypl and Burian (2023) on pages 38–41. The output data layers describing the population distribution in the specific research area are visualized in Fig. 2 with variant differentiation of daily and night population states.

After presenting a global view of the population distribution in the specific research area, it is convenient to proceed to a specific population quantification and approximate the differences between day and night at the level of specific municipalities. The summary table (see Table 2) shows for all municipalities in the specific research area the maximum (i.e., maximum pixel value), average (μ), and total (Σ) values of the daytime and nighttime population in the workday condition. Moreover, the total value of the respective state can be compared with the official population value of 2022.

For larger settlements (over 2,000 inhabitants), the table shows a significant difference between the total daily population value and the official estimate for 2022. This is mainly due to the vagueness and ambiguity of data from the Register of Economic Entities in Czechia (Dataset 3 in Table 1). The Discussion section identifies and explains this and other reasons.

The deviations of the projected daily and night population (S_P) from the official population estimate for 2022 (S_e) are shown in Table 3, where a positive (+) deviation indicates an overestimate and a negative (−) underestimate. While the raster reflecting the night population reaches adequate accuracy, in the case of the daily population, the deviation increases significantly with increasing settlement size – the largest overestimation occurs for the most populous settlements, while smaller settlements of up to 1,000 inhabitants are estimated quite faithfully. Given the settlement structure of the specific research area (i.e. the dominance of smaller settlements), the deviations were considered adequate for the research design. However, to remove the adverse effect of larger settlements, average deviations will be subtracted at the level of individual municipalities to achieve the highest possible accuracy. It should be noted that the usual residence is compared with the official population estimate based on permanent residence – deviations at a reasonable level are, therefore, perfectly natural.

3.2. Creation of the questionnaire survey

Adequate data were necessary to assess and evaluate mosquito activity in the Litovelské Pomoraví and the impacts of this activity on humans. Due to the phenomenon's nature, a questionnaire survey was decided upon, as mosquito activity is related to humans and cannot be measured by instruments directly in the field and expressed in conventional quantities. Combined with the population distribution data, it is then possible to quantify the population in areas with increased mosquito activity and take measures leading to an increase in the quality of life in this specific research area.

The essential requirements for the technical platform are the ability to draw on the map (point and area features) and to relate data to this relevant location in space (detailed map required). It is also necessary to ensure the conditional behavior of the questionnaire. Simply asking questions, selecting from predefined answers, and writing the answer in a text field are now standard in most form-building platforms. In line with the previously formulated requirements and the questionnaire structure outlined above, the Pocitové mapy platform (Emotional maps) was chosen for the subject survey – concrete example in Fig. 3. ArcGIS Survey123 and ODK Collect could also be used.

The questionnaire was intuitive and user-friendly. The respondent first marked on the map in the form of a point or area the places where he/she is aware of increased mosquito activity, and for each defined place respondent specified the level of activity on a scale of low, rather low, rather high, high or not assessable via a pop-up window – both for the spring and summer months and in aggregate for the year 2023. The respondent then proceeded to fill in the general form, providing personal data in addition to the socio-demographic classification of the respondent (age, gender, place of residence). The questionnaire consisted of the following questions (*the prescribed answer options are given in brackets*).

- Concerning the specific research area, which population group do you belong to? (*permanent resident*; *secondary housing owner or user*; *visitor-tourist*),
- Indicate the level to which mosquito activity limits you during your stay in the specific research area. (*does not limit*; *rather does not limit*; *rather limits*; *limits*),

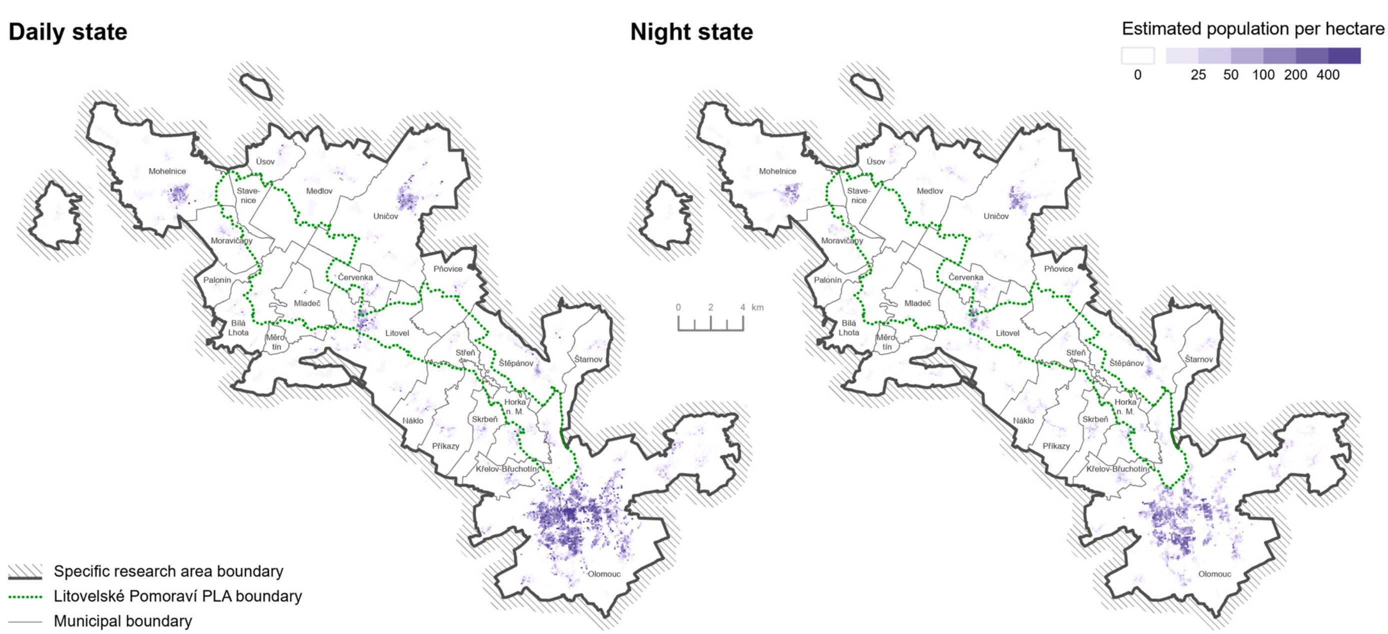

Fig. 2. Population distribution in the specific research area.

Table 2
Summary of daily and night population distribution in the municipalities of the specific research area

Municipality	Population (2022)	Daily state of population			Night state of population		
		max.	μ	Σ	max.	μ	Σ
Olomouc	99,496	7,503	25.72	265,860	1,563	10.20	105,419
Uničov	11,066	2,259	3.88	18,520	266	2.27	10,963
Litovel	9,567	768	3.39	15,758	297	2.04	9,477
Mohelnice	9,103	3,503	3.61	16,701	309	1.98	9,143
Štěpánov	3,512	1,076	2.09	5,583	112	1.26	3,385
Horka nad Moravou	2,577	656	3.23	3,866	90	2.07	2,475
Křelov-Břuchotín	1,749	378	3.11	2,464	68	2.21	1,752
Medlov	1,626	175	0.61	1,902	53	0.50	1,570
Náklo	1,504	326	1.60	1,831	50	1.26	1,445
Červenka	1,445	264	1.82	2,060	115	1.31	1,490
Moravičany	1,324	92	1.25	1,515	48	1.02	1,240
Příkazy	1,316	186	1.13	1,584	46	0.90	1,263
Skrbeň	1,160	137	1.74	1,363	72	1.42	1,115
Bílá Lhota	1,152	186	0.70	1,283	36	0.61	1,106
Úsov	1,139	241	1.34	1,252	57	1.17	1,087
Pňovice	1,010	208	0.80	1,317	50	0.60	988
Štarnov	846	68	0.89	884	46	0.83	819
Mladeč	716	221	0.86	1,033	93	0.63	754
Střeň	600	76	0,83	487	40	0,99	582
Palonín	351	73	0,62	331	32	0,62	331
Měrotín	263	28	1,16	251	25	1,17	252
Stavenice	135	27	0,24	157	22	0,20	127

Table 3
Deviation of the projected population from the official 2022 population count

Settlement category by population	Mean deviation $S_P - S_e$	
	Daily state	Night state
< 1 000	+100.57	−1.55
⟨1 000; 2 000)	+515.10	−31.03
⟨2 000; 5 000)	+1,336.16	−88.87
⟨5 000; 10 000)	+4,879.00	−104.00
⟨10 000; 15 000)	+8,987.25	−43.00
> 15 000	+5,8258.2	+1,259.4

- How do you try to reduce/limit/eliminate mosquito activity? (*use of repellents*; *contact killing at the site of occurrence*; *cancellation of visit/stay or rescheduling*; *otherwise*),
- How do you assess mosquito activity in a specific research area in the long term? (*worsens*; *rather worsens*; *no change*; *rather improves*; *improves*; *cannot assess*),
- Are you getting enough information about mosquito calamities in Litovelské Pomoraví? (*yes, to an adequate extent*; *yes, but i would like more information*; *no*).

If the respondent has signed up for the visitor/tourist group, he/she

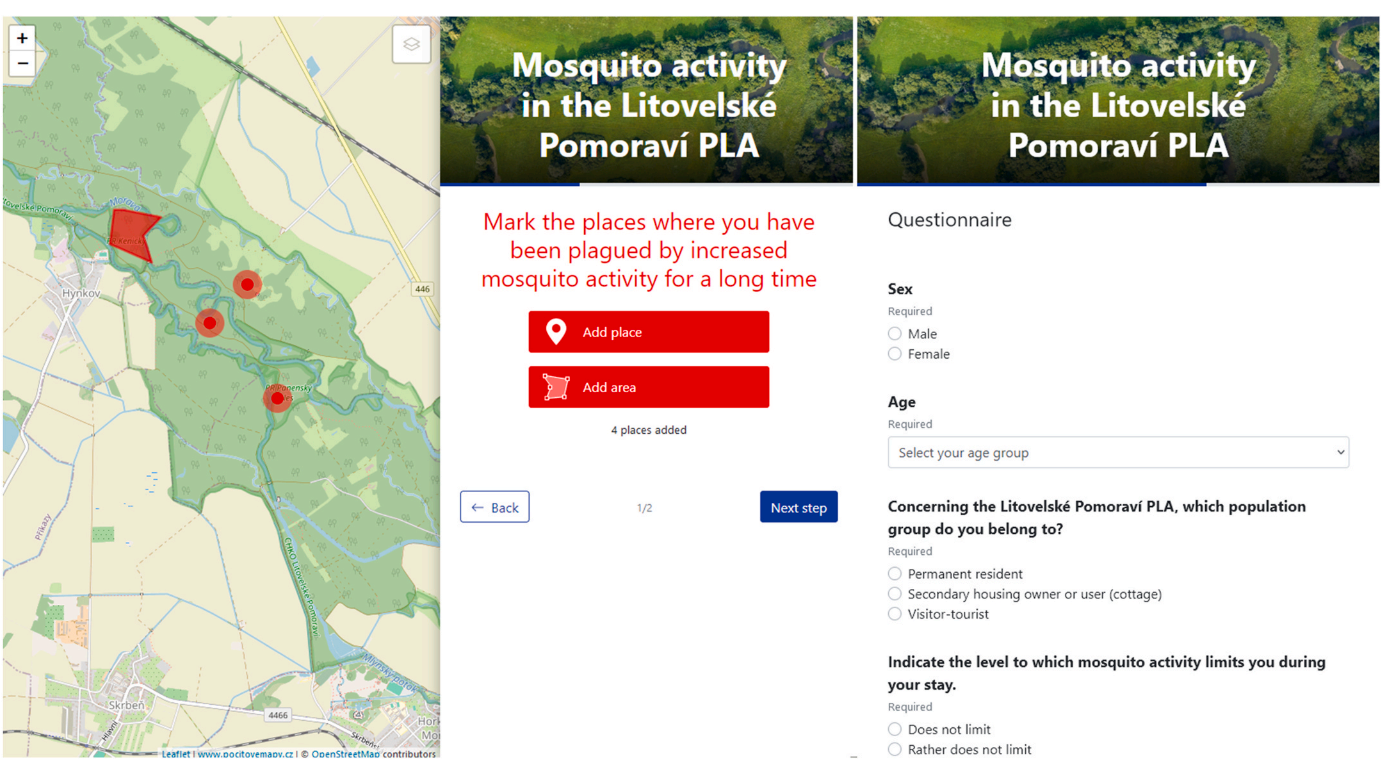

Fig. 3. Sample online questionnaire with map (originally in Czech; translated).

has also answered the following questions.

- How often do you visit a specific research area in the summer? (*less than 3 times* per *month*; *3 to 6 times* per *month*; *7 to 10 times* per *month*; *11 to 14 times* per *month*; *15 or more times* per *month*)
- What is the usual purpose of your visit? (*hiking*; *water recreation/swimming*; *cycling or inline*; *other purpose of visit*)

3.3. Questionnaire evaluation, identification of active zones and quantification of the affected population

In the initial phase, data export and filtering of records of respondents residing outside the specific research area was carried out – these were mainly 43 respondents permanently living in Hlušovice, a village located outside the specific research area (respondents from Hlušovice reported as visitors-tourists were, however, in the respondent's sample).

Subsequently, a general evaluation of the results of the respondents' form data was carried out, consisted of constructing graphs and charts in a spreadsheet environment, using pivot tables.

However, the main focus was on the extensive phase of delineating active zones. The key input attributes were mosquito activity data in the spring and summer months, mosquito activity data in 2023, and the corresponding geometries (points, polygons) related to these data. First, a numerical rating was made for each (partial) mosquito activity degree according to Table 4, where the individual word labels for the states were numerically scaled by values from the interval $\langle 1; 5 \rangle$, thus creating the new variables I_{spring}, I_{summer} and I_{2023}.

The values of these partial mosquito activity degrees were also averaged to produce a single aggregate value $I_{\overline{x}}$ reflecting seasonal variability, for which $I_{\overline{x}} = \frac{I_{spring} + I_{summer} + I_{2023}}{3}$, where $I \in \langle 1; 5 \rangle$. The transformation of the word states to numbers, together with the calculation of the aggregate value, was successively applied separately to both polygon and point records.

Then, records with polygon geometry – separately for each of the variables I_{spring}, I_{summer}, I_{2023} and $I_{\overline{x}}$ – were unioned and aggregated by area. The arithmetic mean was calculated for the overlapping (identical) areas, which resulted in a compromise valuation of the sub-areas across respondents (hereafter referred to as the **a-value**). The issue of overlapping geometries did not need to be addressed for the point records, so the original values of I_{spring}, I_{summer}, $I_{\overline{x}}$; were further assumed **(b-value)**.

In the next phase, a regular square grid with a spatial resolution of 100 m × 100 m was generated with the reference parameters used to create of the population grid. The spatial join was then used to assign a-values (polygons) to individual grid cells, and a similar process was followed for points (b-values). Geometric union followed by c-value creation produced the resulting mosquito activity degree value with resolution to individual grid cells **(c-value)**. The formation of the c-value was carried out according to the following criteria.

- If the a-value and b-value are defined, then calculate the c-value as the arithmetic mean of the a-value and b-value;
- If a-value is defined and b-value is not defined, then c-value is equal to a-value;
- If b-value is defined and a-value is not defined, then c-value is equal to b-value;
- If neither a-value nor b-value are defined, then c-value is also not defined;

Whereby this part of the procedure was performed repeatedly for I_{spring}, I_{summer} and $I_{\overline{x}}$. Since a-values and b-values are defined on the interval, a zero value cannot occur. The resulting mosquito activity rasters then use the following scaling intervals (see Table 5).

The diagram in Fig. 4 simplifies the process of formation of the active zone layer.

In addition to the baseline layer of active zones, a variant was created that reflects the location of mosquito breeding grounds identified within the prediction and management of calamitous mosquito populations project (more information in the Funding section) into the originally defined active zones resulting from the questionnaire survey. The envelope zones created through buffering at distances of 100, 500 and 1000 m from the geometric center of the breeding grounds, after conversion to a raster and reclassification, were coded with the numbers 3 (for 100 m), 2 (for 500 m) and 1 (for 1000 m) according to their predicted threat. For example, the nearest pools are weighted at 3, and the furthest pools are only assigned a weight of 1. The grid resolution of the envelope zones is consistent with that of the population grid, i.e., the size of a single cell corresponds to 100 m × 100 m. The total active zone score was then simply given by multiplying the original active zones $\langle 1; 5 \rangle$ with the raster of the envelope zones of the pools in the interval $\langle 1; 3 \rangle$. The resulting continuous variable of the total score, defined by the interval $\langle 1; 15 \rangle$, was divided by the natural breaks into five groups in the visualization, characterized by minimal within-group differentiation and, conversely, by the greatest possible differences between the groups themselves. This configuration ensured the differentiation of high-activity to low-activity areas, crucial for interpreting the resulting data and further inference.

The final quantification of the affected population was then performed using the zonal statistics, where the input raster of values was the population raster (in the daily and night state variant), and the newly created active zone raster (c-value – respectively total score – in the spring and summer, and overall trend variants) was used as the zone raster.

The creation of population threat degrees for daily and night population states was based on the min-max normalization of population state values and mosquito activity degree (total score) by the formula $y_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)}$, where y_{ij} is the new transformed value of the variable, x_{ij} corresponds to the i value of the variable j and x_j corresponds to the set of all values of the variable j – in combination with the function *min*, *max* means the minimum or maximum value of the set of all values of the variable x_j; then multiplying them. Visualization of the mosquito-threat population can be used to visually identify a group of breeding grounds where eradication measures are to be carried out as a priority, with the goal of improving the quality of life of people in mosquito-threatened populated areas.

4. Results

One hundred five respondents participated in the survey, 48 of

Table 4
Numerical rating of the states forming the partial mosquito activity degree

Partial mosquito activity degree (consolidated for spring, summer, year 2023)	Score
Cannot be determined or not filled in	1
Low	2
Rather low	3
Rather high	4
High	5

Table 5
Scaling intervals of resulting mosquito activity degree

Mosquito activity degree	Interval (c-value)
Not clearly identifiable	$\langle 0; 1 \rangle$
Low	$\langle 1; 2 \rangle$
Rather low	$\langle 2; 3 \rangle$
Rather high	$\langle 3; 4 \rangle$
High	$\langle 4; 5 \rangle$

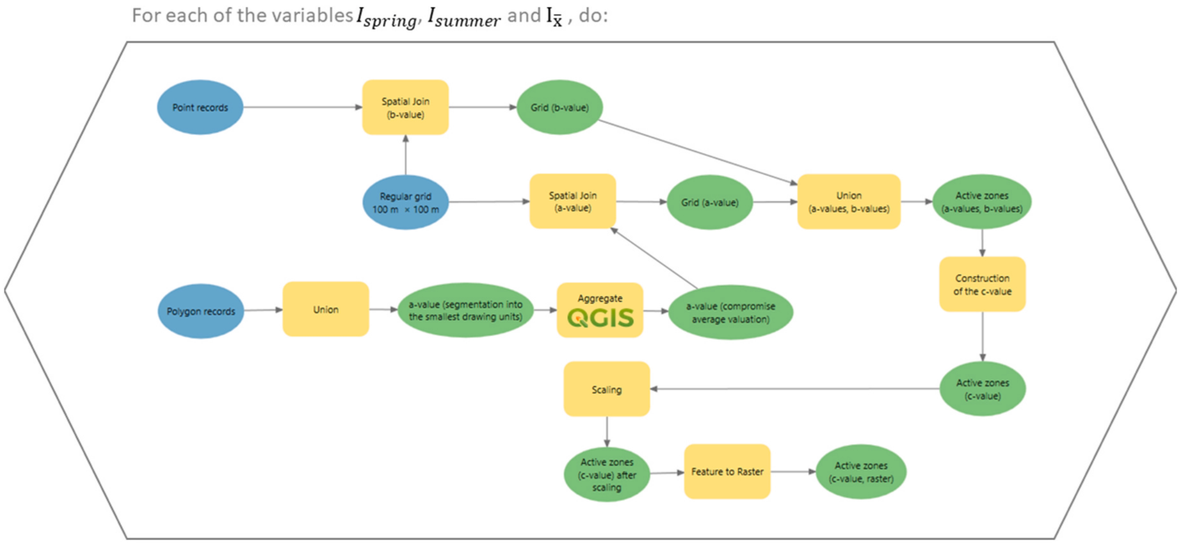

Fig. 4. Simplified diagram of the active zone layers process in GIS environment.

whom were men and 57 of whom were women. Across genders, the most commonly represented age groups were 46–55 (10 female, 17 male), 36–45 (15 female, 10 male respondents), and 26–35 (10 male and 8 female respondents).

As seen in Fig. 5, most of the surveyed population comprised residents living in the specific research area (88%, 93 residents in absolute numbers). The second largest group, but by a significant margin, comprised visitor-tourists (8% share, i.e. 8 respondents). Secondary housing owners and users then occupied a 4% share (4 respondents). Owners and users of secondary housing and tourists comprise 12% of the surveyed population, so this is a negligible sample.

The largest groups of respondents have declared their affiliation with Horka nad Moravou (33 respondents), Příkazy (22), Střeň (18) and Náklo (11). Other municipalities in the specific research area were mentioned by respondents at least once but no more than four times (Olomouc). Seven residents from Hlušovice – a village located outside the specific research area – were recorded as visitors-tourists.

Visitor-tourists most often stated that they visit the specific research area less than three times per month (4 respondents) or 3–6 times per month (2 respondents). See the graph in Fig. 6 for more details. Regarding the purpose of the visit, cycling and in-line (5 respondents) or hiking (3 respondents) predominate.

Out of 105 respondents, 52 responded that they were limited by mosquito activity in the specific research area (equivalent to half of the sample – 50%). Thirty percent of respondents said they were rather limited by mosquito activity. Respondents with predominantly self-limiting feelings (degrees of limiting and rather limiting combined)

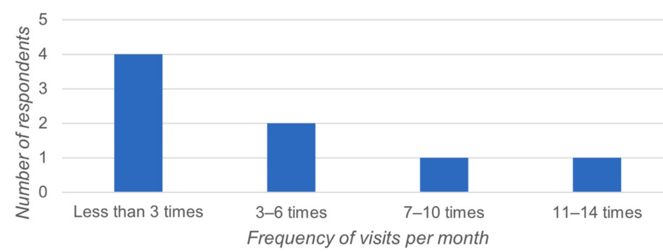

Fig. 6. Frequency of visits by visitors-tourists to the specific research area.

then occupy 80% of the population and constitute a significant majority. The diagram in Fig. 7 indicates the full structure.

Of the measures listed for mosquito control or elimination (Fig. 8), repellents dominate (78 respondents), followed by contact control at the site of occurrence (12 respondents). Five respondents would choose to cancel a visit/stay in a specific research area and/or reschedule a visit. For the other options offered (limiting the time spent outdoors, using different methods, and not taking action), a negligible number of responses are recorded (4 or less).

The highest number of respondents is inclined to believe that mosquito activity in the specific research area does not change over time in the long term. The other grades are almost equal, with three percent of respondents not venturing to assess the situation. As the graph in Fig. 9 illustrates, nearly 40% of respondents marked the "No Change" option in

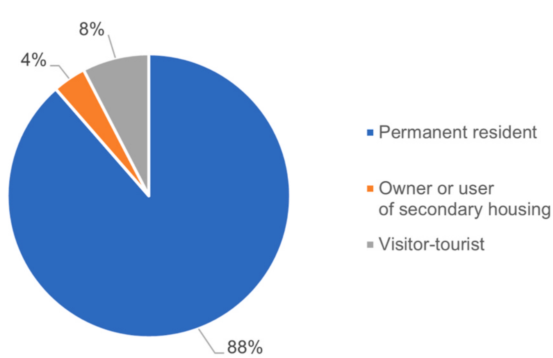

Fig. 5. Respondent structure in relation to the specific research area.

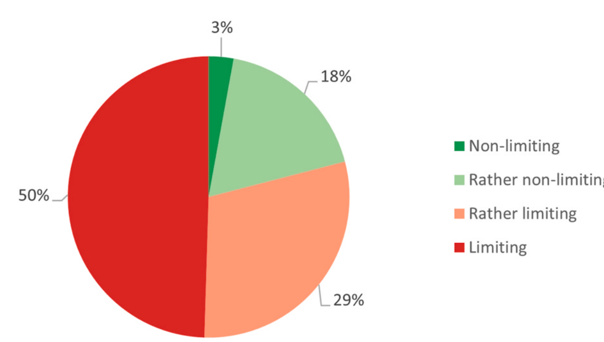

Fig. 7. Mosquito activity and its influence on respondents.

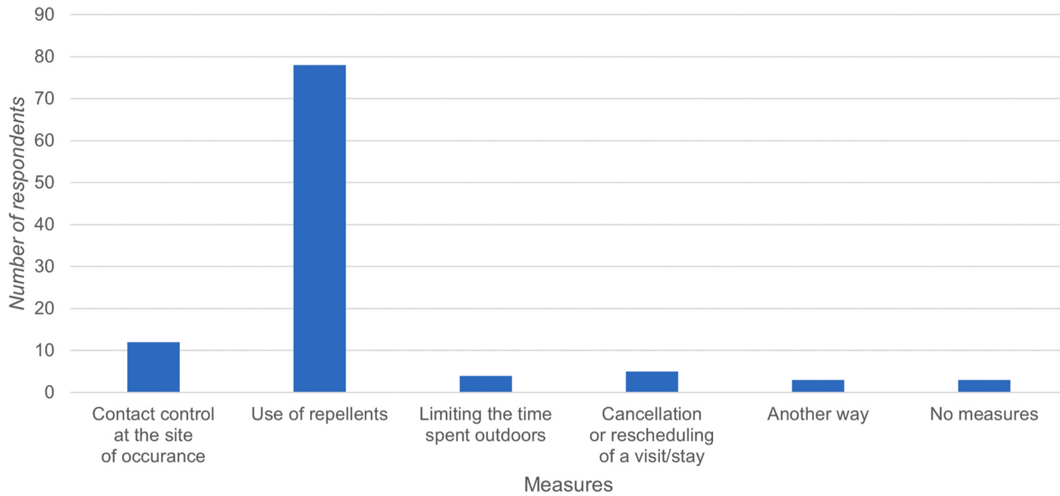

Fig. 8. Measures to reduce or eliminate mosquitoes.

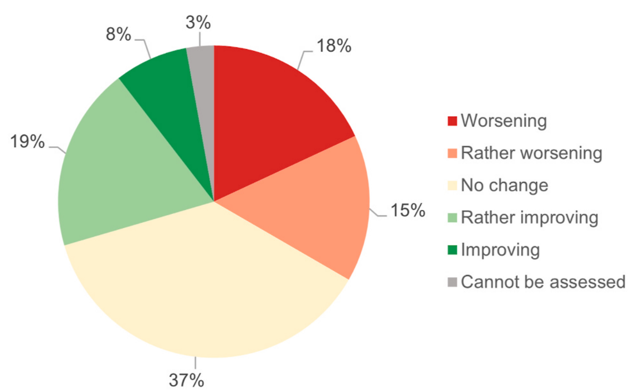

Fig. 9. Mosquito activity and its long-term trend.

the questionnaire. Eighteen percent of respondents believe that the situation is visibly worsening, and fifteen percent lean towards the "Rather worsening" level – a combined 33% share. Approximately 30% of respondents perceive the situation to be improving or rather improving (8% improving, 19% rather improving).

Awareness of mosquito calamity issues (Fig. 10) is insufficient in the specific research area, with more than 50 respondents (i.e., nearly 50% of all respondents) thinking so. Around 30 respondents are fully informed, and 18 receive information on mosquito calamity issues but would like more information.

The most frequently marked places (map in Fig. 11) include the area of the boating camp in Hynkov (part of the Příkazy village), including the immediate surroundings and most of the Horka nad Moravou built-up area on the right bank of the Mlýnský Brook along the border of the protected landscape area. In the northeastern part of the village of Střeň around the Benkovský Brook, a left-side tributary of the Morava River, 8–9 drawings are recorded (the second most numerous category).

The specific research area covers a total area of 465 sq. km (including 93.30 sq. km of the Litovelské Pomoraví PLA), of which the respondents marked 92.53 sq. km as an active area extending both inside and outside the PLA. Based on a combination of the resulting active zone layer and the population grid, the population affected by the respective mosquito activity levels was quantified in Table 6, differentiating between the periods monitored (spring, summer and overall trend).

As Table 6 shows, summer mosquito calamities have a greater impact on the population than spring calamities in terms of area and population numbers. The spring months are dominated by a rather low level of activity, with a total area of about 46 sq. km, affecting nearly 12,000 inhabitants during the day and 4,360 at night. In the months, a high level of activity is the majority, occupying an area of 28.4 sq. km and housing 12,742 and 4217 inhabitants (daytime and nighttime conditions, respectively).

Constructing the overall trend by averaging the spring and summer states together with the 2023 total, it was found that the population most affected during the night state is in high-activity areas (3,456 inhabitants; area 8.06 sq. km). During the daily state, the greatest impact is on the population residing in areas of rather high activity (11,247 inhabitants; 34.91 sq. km).

In the spring months (Fig. 12, top left), rather low-activity areas dominate, occupying more than half of the area. In addition, continuous

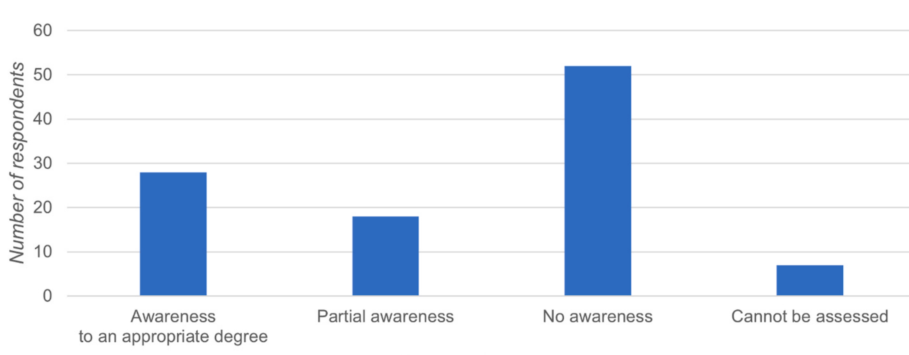

Fig. 10. Awareness of mosquito calamities in specific research area.

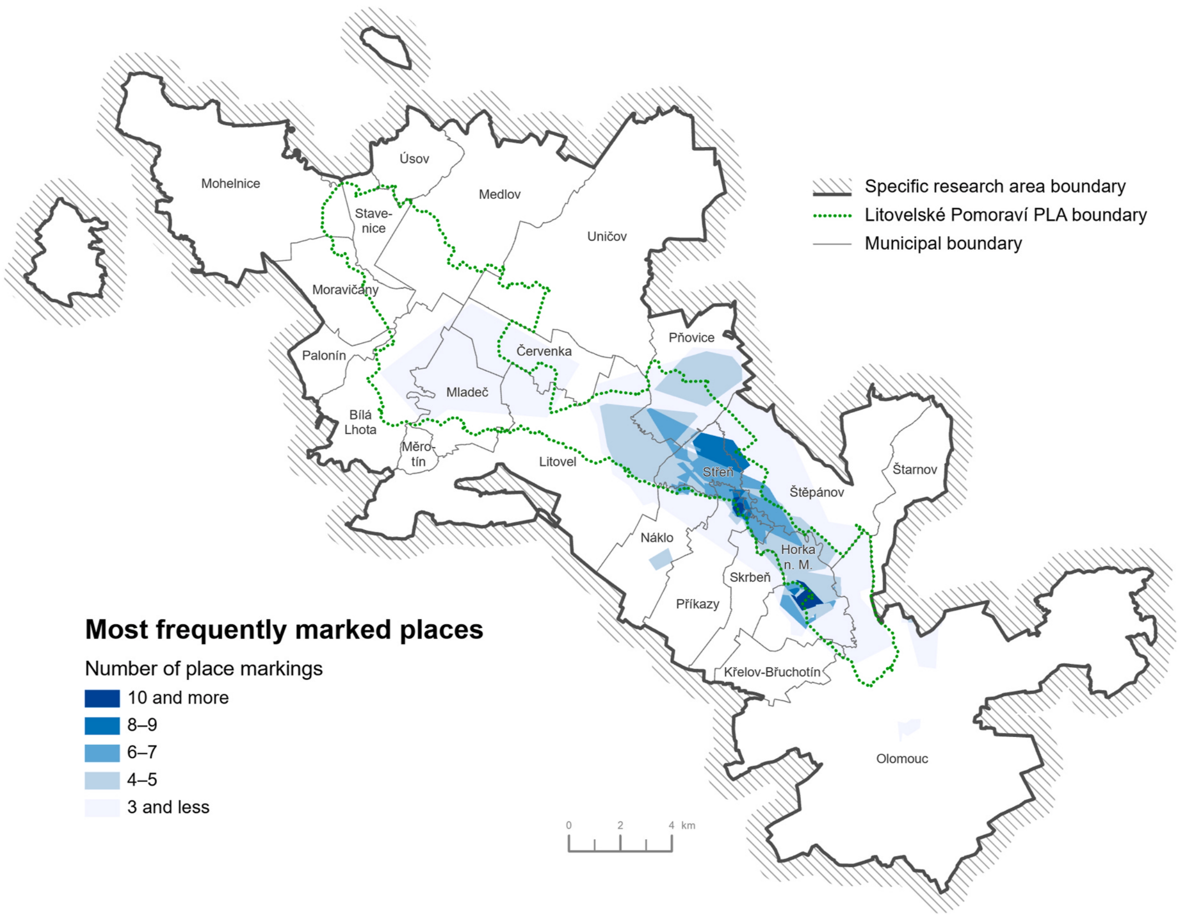

Fig. 11. Most frequently marked places.

Table 6
Activity levels in individual seasons (spring, summer, overall trend) and related areas and population numbers during day and night (highest values of population and areas are orange highlighted).

Activity degree	Spring			Summer			Overall trend normalized by the 2023 state		
	Population		Area (in sq. km)	Population		Area (in sq. km)	Population		Area (in sq. km)
	Daily state	Night state		Daily state	Night state		Daily state	Night state	
High	31	54	2.43	12,742	4,217	28.42	2,715	3,456	8.06
Rather high	2,636	2,886	11.28	1,359	2,490	25.59	11,247	2,024	34.91
Rather low	11,888	4,360	45.50	987	612	10.93	951	40	21.59
Low	102	568	9.15	102	36	2.81	102	2,961	3.81
Not clearly identifiable	2,049	2,972	24.17	2,840	3,485	24.78	1,983	2,359	24.16
Total	**16,706**	**10,840**	**92.53**	**18,030**	**10,840**	**92.52**	**16,999**	**10,840**	**92.53**

bands of rather high activity can be found on the territory of the municipalities of Štěpánov, Horka na Moravě, Střeň and Pňovice. High grades can be found only in the minority – in the northern part of Olomouc (in the local part of Chomoutov towards the Chomoutov Lake and the Černovír peat bog) and in Horka nad Moravou.

In the summer months (Fig. 12, top right), there is an obvious increase in active high-level zones in most of the territory of Štěpánov and parts of the territory of Pňovice, Skrbeň, Příkazy, Náklo and Litovel – always in the area adjacent to the border of the protected area. Hot spots of the same grade can then be found fragmentarily within the PLA.

In the case of capturing the overall trend (Fig. 12, down), the areas of high activity level are located in the municipalities of Příkazy (northeast

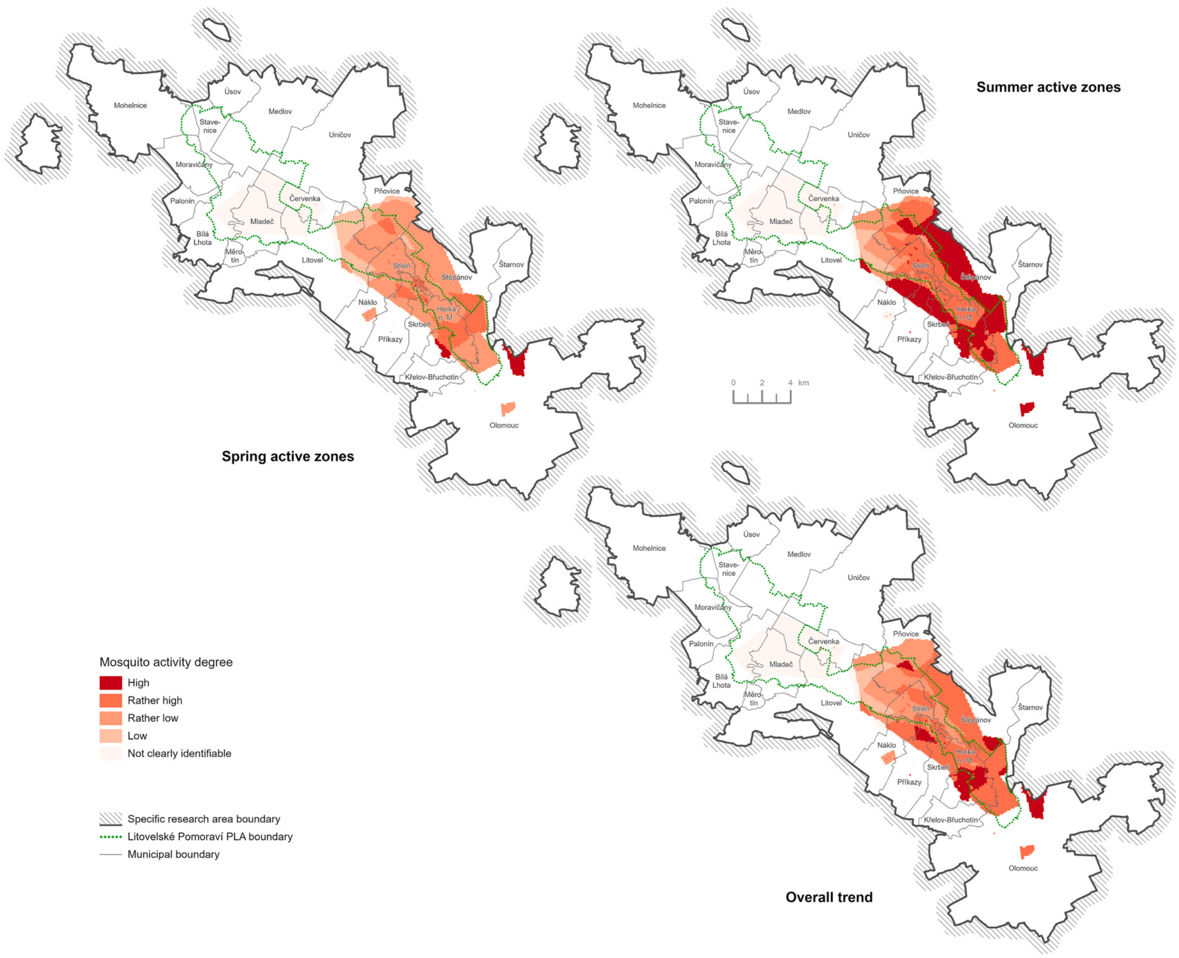

Fig. 12. Spatial distribution of active zones (delineation by respondents' drawing).

of the municipality – local part of Hynkov), Horka nad Moravou (built-up area), Pňovice (Kobylník locality), Štěpánov (area towards Chomoutov Lake) and the northern part of Olomouc (Chomoutov towards Chomoutov Lake and Černovír peat bog). Extensive areas of rather high activity (in relation to areas of rather low activity) are located in the municipalities of Štěpánov, Horka nad Moravou, Náklo, Střeň, Skrbeň and Příkazy – usually at the boundary of the PLA and close to water bodies and streams. According to the respondents, low mosquito activity is typical for the north-western part of the Litovelské Pomoraví PLA, specifically on the Litovel – Pňovice and Litovel – Střeň axes. Areas with ambiguous activity are recorded in the Červenka and Mladeč parts of the municipality.

The existing definition of active zones is burdened by respondents' subjective perceptions, who tend to mark mainly areas in continuously populated spaces where they occur daily (Fig. 12). On the other hand, the objective aspect must also be considered, where the highest activity level is expected in the immediate surroundings of mosquito breeding grounds. Therefore, a new final delineation of the active zones has been made (Fig. 13), which simultaneously considers the data from the questionnaire survey and the location of the mosquito breeding grounds.

An obvious difference from the previous delineation is the shift of areas of high activity from the urbanized parts towards the interior of the integral part of the PLA. In contrast, the adjacent populated parts where direct population contact with mosquito activity is potentially possible have generally decreased one activity level and fragmented continuous areas into smaller units. Outside an integral part of the PLA, high-activity areas have newly emerged in the northern part of the Náklo. The area in the north part of Olomouc remained almost unchanged. Inside the PLA, areas of high activity can be observed in a fragmented manner in the areas of Střeň, Horka nad Moravou and Pňovice.

As seen from Table 7, the largest part of the population is concentrated in areas of rather high activity during the day (2,745 inhabitants) and in areas of medium activity during the night (2,309 inhabitants). The high-activity areas are minimally populated (743 inhabitants in the daytime and 263 at night). The most extensive areas, although not continuous, are the areas of rather high activity, which cover an area of approximately 25 sq. km.

Fig. 14 shows areas of mosquito-threatened populations during the day and night. These areas are spatially delineated and visualized in context with the figural marks of mosquito breeding grounds. In addition to the number of inhabitants in a grid cell, the degree of population threat is also determined by the cell's mosquito active zone.

For the daily state (Fig. 14, left), typical hotspots with high-threatened populations are surrounded by cells with a significantly low-threatened population (workplaces and schools versus empty dwellings with representatives of the post-reproduction group). In contrast, in the night state (Fig. 14, right), an increase in the threatened population (human dwellings) can be observed, which usually forms larger continuous areas. These visualizations intend to highlight, at the level of daily and night population state, the areas with the most threatened populations – i.e., to identify places in the vicinity of which priority measures to improve the quality of life of the inhabitants (e.g. application of larvicides in adjacent mosquito breeding grounds) are necessary rather than to express exactly the population status in each grid cell.

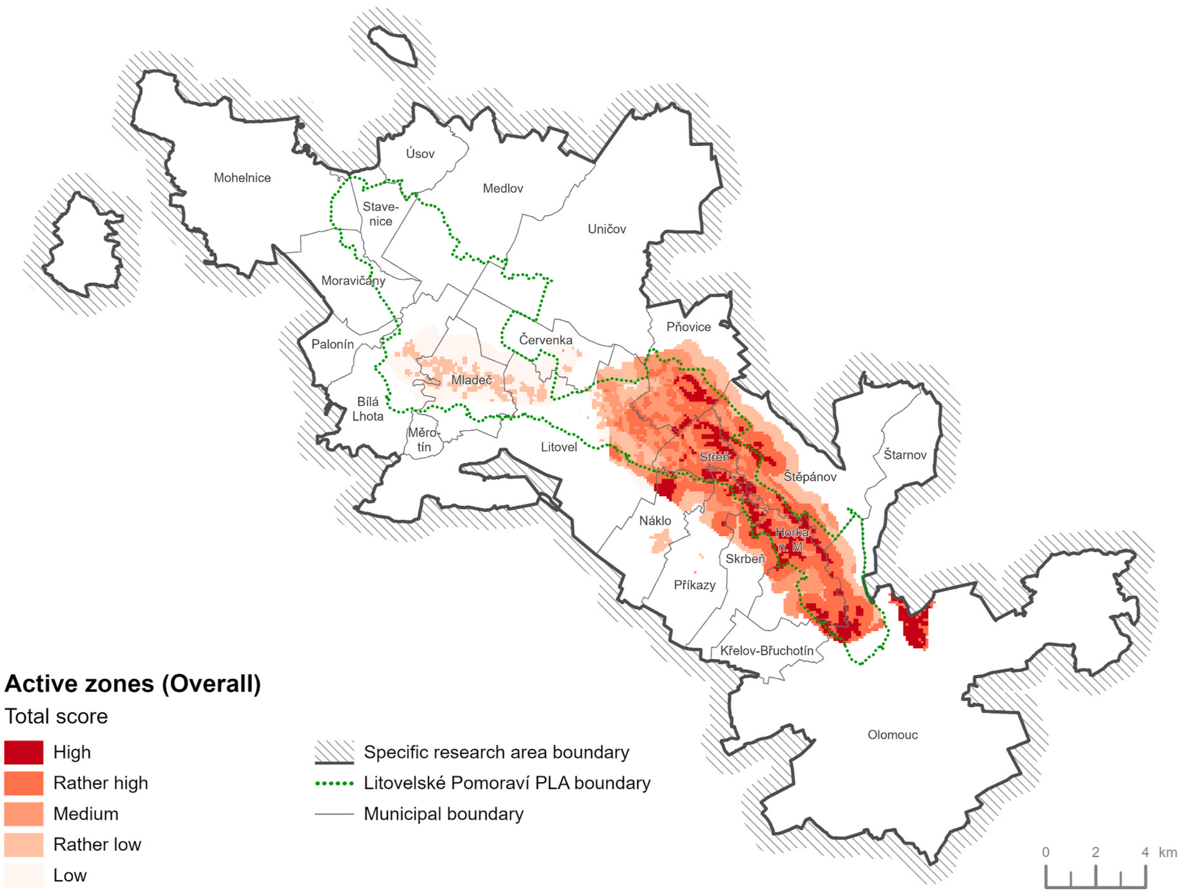

Fig. 13. Overall spatial distribution of active zones (delineation by respondents' drawing and actual breeding grounds locations).

Table 7
Total score categories and corresponding areas and population numbers for daily and night states (highest values of population and areas are orange highlighted).

Total score as a combination of the factors: *distance from the breeding ground, activity level*		**Overall trend** normalized by the 2023 state		
		Population		**Area** (in sq. km)
Category (verbal expression)	**Interval**	Daily state	Night state	
High	(10; 15⟩	743	263	9.77
Rather high	(6; 10⟩	2,745	2,095	24.83
Medium	(4; 6⟩	2,162	2,309	13.68
Rather low	(2; 4⟩	1,294	1,347	17.17
Low	(1; 2⟩	2,422	3,177	13.35
Total		**9,366**	**9,191**	**78.80**

5. Discussion

A substantial part of the discussion can be conducted on two levels – concerning the layer of population distribution, the subjective aspect of defining the active zones, and the nature of socio-economic research in general.

A fundamental aspect that is not usually taken into account when describing the distribution of the population in an area is the dependence on the time of day – the distribution of the population varies during the day, at night, on weekdays and at weekends. In contrast to traditional approaches (e.g., simply using a permanently living population at the address level), alternative approaches have been used to describe the population distribution during the workday's daytime and nighttime. Implementing the weekend conditions is problematic because the population's behavior depends, among other things, on the tourist attractions and infrastructure of the territory, i.e., the very nature of the territory and other hidden specificities determine it. Their description is complicated because there is no conventional register or dataset to assess it in a standardized way, and it is technically challenging to ensure the actual "counting" of people outside populated

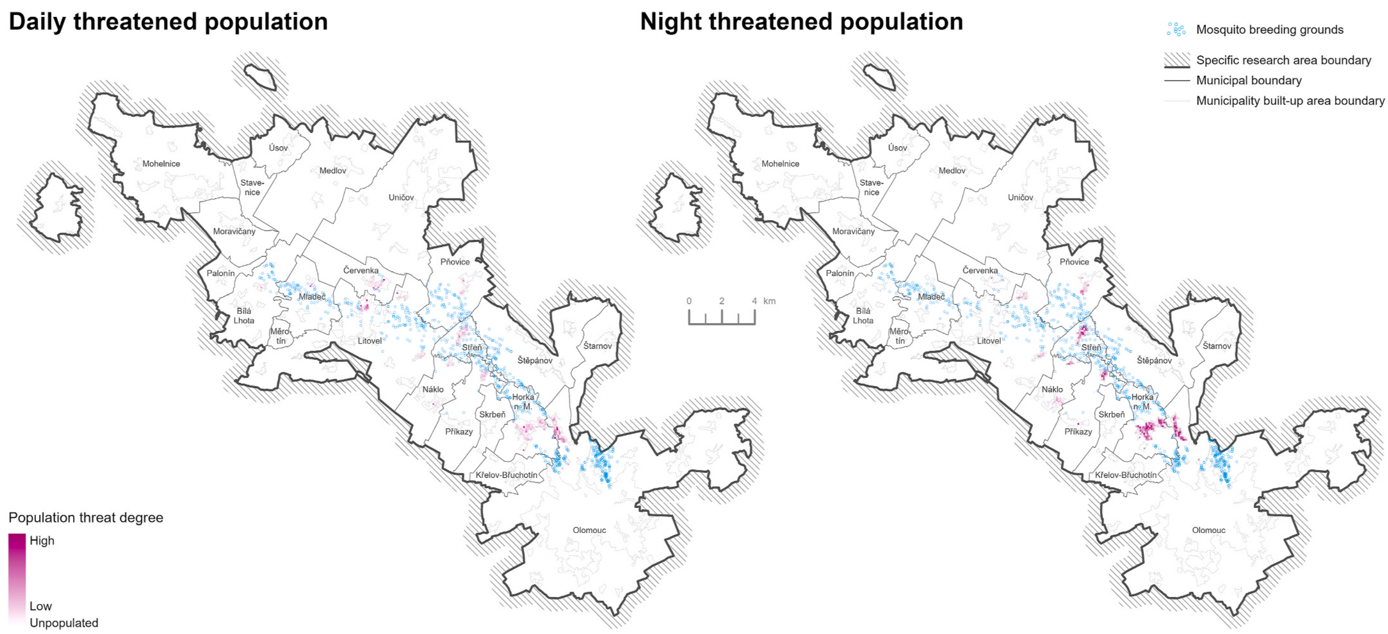

Fig. 14. Spatial distribution of the threatened population during the daily and night state.

areas (Rypl and Burian, 2023).

In the context of the presented representative layer of population distribution, problems related to the input data's lack of detail and uncertainty can be discussed. As already mentioned, a major weakness of the population grid used is represented by the sub-data on the number of workers and employees from the Register of Economic Entities (see Dataset 3 in Table 1), where it is not possible to reliably distinguish between the seat of the entity and its sub-establishments. Therefore, when constructing the population grid, the corresponding value of the number of employees of an entity located in a specific research area, in some cases, included employees from branches/operations located outside this area. This deficiency is compounded by the fact that the data are given only as an interval instead of an exact numerical value. These facts have then caused a steep increase in the values of the daily population distribution, which is most pronounced for large settlements (towns or cities). At the same time, smaller settlements of up to a thousand inhabitants are determined faithfully. Following the authors' original methodology, these weaknesses have been compensated by subtracting the deviation from the corresponding daily population state. Given the absence of a larger number of towns and only the marginal intervention of Olomouc (the largest city in the specific research area/ region), this solution is satisfactory. The night-time population figures achieve adequate accuracy. It is important to note that the validation compares usual residence, including foreigners, with the official population estimate based on permanent residence – variations at a reasonable level are thus perfectly natural.

Moreover, the methodology assumes 100% presence of all workers at the workplace at one time, as well as all children and pupils in educational institutions, which is never achieved. Furthermore, it is necessary to note that this figure does not only include the population of the municipality to which it refers but also the population from other municipalities (e.g. in Olomouc – the largest city in a specific research area – people are studying, working, staying in social institutions, and also people from the surrounding area who are not normally counted among the residents), together with from surrounding regions who commute to the specific research area for work.

The questionnaire survey was conducted to obtain information on mosquito activity and its impact on the population, which is undoubtedly burdened with a certain degree of subjectivity. Each respondent has a personal perception, and the idea of what low, rather low, rather high and high mosquito activity means varies slightly across respondents. However, a questionnaire and possibly a personal interview are the only means of gathering and locating information about this phenomenon in space. The survey's subjectivity was considered when defining the active zones – hence the choice of an aggregation function by the mean to compensate for any differences in perceived activity.

Another specificity of the questionnaire survey data is the respondents' natural tendency to mark on the map mainly places in populated parts of the territory, i.e., places where they are in daily contact with mosquitoes. In contrast, there is an objective perspective of the phenomenon, which assumes that theoretically, the highest activity is near mosquito breeding grounds, often located inside protected landscape area far from the built-up areas of villages and towns. Therefore, in the final design of the active zones, both aspects were combined to ensure that the resulting construct reflects the real situation in the area as much as possible.

One can also discuss the stratified distribution of respondents across the municipalities of the specific research area, balanced representation of men and women, equal representation of age categories and categories of respondents according to their relationship to the subject area. Ensuring a complete sample of respondents in human geographic research is often very difficult. Although the respondent base could be considerably broader for some municipalities, the results presented can be considered adequate for the stated research purpose and a true reflection of the actual situation. The ratio of men and women is balanced (women slightly predominate), as is the distribution of age groups across the sexes (though more varied for men). While the predominance of permanent residents makes it impossible to compare the differences in perceptions of activity between groups of respondents, it highlights the perceptions of local people who know the situation in the area best – and can reliably locate, describe and assess it.

For a thorough assessment of the development of the situation, especially concerning climate change, it would be beneficial to repeat the questionnaire survey with a mapping of mosquito calamity hotspots periodically in the coming years, which would allow monitoring changes over time and the development of the overall situation, including verification of the spatial extent of active zones. This would enable a more dynamic understanding of the problem and the development of a more effective long-term management strategy.

The territory is specific in its diversity and number of breeding grounds. The study was carried out during the prediction and management of the mosquito calamities project, where, in addition to information from citizens living in the area, a range of data about the area was collected, including LIDAR scanning, aerial photography, and installation of sensors in the area. Management without aerial application of products is very limited due to the size of the area and the number of breeding grounds.

Although the survey was carried out in one fixed period, it provides information on the long-term situation in the area. The definition of the active zones itself is based on data from residents who live permanently in the specific research area and know it in detail, which guarantees a faithful representation of the situation on a long-term scale. Therefore, repeating the survey would only make sense if mosquito locations were regularly mapped, which is complicated and time-consuming. It cannot be ruled out that newly mapped breeding sites would again show a certain degree of outdatedness immediately after the mapping was completed. The associated location of the mosquito breeding grounds often varies in the specific study area. Yet, the position relative to the identified hotspots does not change much – the expected variability is on the order of tens to hundreds of meters.

The study was carried out to capture a long-term condition, so it is minimally affected by the actual situation in 2023 when targeted calamity management was carried out. Therefore, the findings and results are adequate and consistent with the stated objectives and the stated concept of integrated management of the area.

6. Conclusion

The paper focused on the novel assessment of mosquito activity and its impact on the population in the territory of the municipalities in the Litovelské Pomoraví PLA. The fulfilment of the set objectives A–D was achieved through three segments – the design and creation of representative population distribution layers, the design and creation of a survey questionnaire, and an overarching segment that integrates the previous two segments and uses them to identify active zones and quantify affected population.

In the segment of **designing and creating a representative population distribution data layer**, a methodology was presented based on the premise of population variability during the day and night as well as on weekdays and weekends. Two variants of the population grid were created using data from Czech national registers – the daily and night states of the working day – because the weekend state is difficult to implement to express the population distribution of the specific research area. Besides visualizing the layers as a grid, the population was quantified at the level of individual villages with specific numbers for day and night. Due to the high overestimation of the daytime population, corrections were made in the form of identifying the average deviation and subtracting it from the corresponding population states.

In the segment of the **design and development of the questionnaire survey segment** implemented to obtain information on mosquito activity and its impact on the population, the requirements were generally formulated, and the structure of the questionnaire and its operation (use) were described. The Pocitové mapy platform (known in English as Emotional Maps) combined a traditional question form and a detailed web map, in which locations can be marked as points and areas.

In the follow-up phase, non-spatial and spatial analysis of the questionnaire data was carried out, culminating in integrating **the outputs of the two previous segments**. Within results evaluation, **which fulfilled objectives A** and **B**, was found, mosquito activity limits residents and visitors to the specific research area. From a long-term perspective, the activity level is neither improving nor worsening, disproving **hypothesis I**. Of the measures cited for mosquito control or elimination, repellents dominate, followed by contact control at the site of occurrence. By integrating population grids describing the distribution of the population in the specific research area and data from the questionnaire survey, the identification of active zones and the quantification of the threatened population was made. This processing procedure was presented both at the level of methodological steps and at the level of technical implementation in the GIS. First, the numerical variables expressing the mosquito activity degree were calculated based on point and polygon data from the questionnaire survey. Then, the data was aggregated by mean and area, which led to the definition of active zones in several variants – spring, summer, and overall.

Regarding the combination of the resulting active zone layer and the population grid, the population affected by the respective mosquito activity levels was quantified, differentiating between the periods monitored (spring, summer and overall trend). This yielded **confirmation of hypothesis II**, as it was found that summer mosquito calamities have a greater impact on the population than spring calamities, both in terms of area and population numbers.

During the spring months, relatively low activity levels prevailed over a total area of about 46 sq. km, affecting nearly 12,000 inhabitants during the day and 4,360 inhabitants at night. In contrast, high activity levels prevailed in the summer, covering an area of 28.4 sq. km and affecting 12,742 and 4,217 inhabitants (day and night, respectively). Based on the construction of the overall trend by averaging the spring and summer conditions together with the 2023 total condition, it was found that the population living in areas with high activity during the night condition would be the most affected (3,456 inhabitants; area 8.06 sq. km). During the day condition, the population living in areas with rather high activity would be the most affected (11,247 inhabitants; area 34.91 sq. km). As well as the population numbers, the spatial extent of the active zones was defined.

Since the active zones defined based on the questionnaire survey data are burdened by the subjectivity of respondents, who tend to identify main areas in continuously inhabited spaces where they occur daily, the objective aspect of assuming the highest activity near mosquito breeding grounds was also considered. This led to a new definition of active zones. An obvious difference from the previous delineation is the shift of areas of high activity from the urbanized parts towards the interior of the integral part of the PLA. In contrast, the adjacent populated parts where direct population contact with mosquito activity is potentially possible have generally decreased one activity level and fragmented continuous areas into smaller units. The largest part of the population is concentrated in areas of rather high activity during the day (2,745 inhabitants) and in areas of medium activity during the night (2,309 inhabitants). The high-activity areas are minimally populated (743 inhabitants in the daytime and 263 at night). The most extensive areas, although not continuous, are the areas of rather high activity, which cover an area of approximately 25 sq. km. **Objective C has thus been met**.

Finally, under **objective D**, mosquito-threatened population areas were identified during the day and night. The threat degree based on the number of inhabitants was also determined again by mosquito activity and distance from breeding grounds. Visualization can be used to visually identify a group of breeding grounds where eradication measures are to be carried out as a priority to improve the quality of life of people in mosquito-threatened populated areas.

The methodology and innovative procedures using geoparticipation and GIS presented are universally valid and can be applied repeatedly, regardless of the specific requirements for the shape and size of the area or the detail of the input data, when dealing with integrated management of the area to map mosquito calamity hotspots, assess the situation and take appropriate steps concerning the environment and in favor of the local population.

CRediT authorship contribution statement

Oldřich Rypl: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **Jaroslav Burian:** Writing – review & editing, Visualization, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Jiří Pánek:** Writing – review & editing, Supervision, Data curation. **Jan Brus:** Writing – review & editing, Visualization, Supervision, Project administration, Funding acquisition, Formal analysis, Data curation, Conceptualization.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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