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Landscape-Structure Determined Mosquito Diversity in Hungary (Central-Europe)

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Abstract The present research examined the potential background variables of the high species richness and diversity of the Hungarian (Central-Europe) mosquitoes. The local fauna including 50 species is more diverse than it could be predicted on the climatic and zoogeographical characteristics. The results showed that high species- and life-form diversity of the Hungarian mosquito fauna originated from the relatively high landscape diversity of the humid habitats.

Keywords Mosquito; Fauna; Species; Diversity; Landscape-structure; Life-forms; Humid habitats

Introduction

Climatic capabilities cause that 85 percent of the known mosquito species occur on the Neotropical, Oriental, Afrotropical and Australasian zoogeographical regions (Rueda, 2008). Palaearctic and Nearctic regions are species-poor from this point of view, further the species numbers of the local faunas decrease from south to north. Some area, e.g. the Central-European Hungary, outstands from this trend with their high mosquito diversity. Over the general overview of the Hungarian mosquito fauna the paper examines the potential background variables of this local species richness. The preliminaries of this synthesis and the applied methods are amplified at the thematic compartments.

1 Diversity of the Hungarian mosquito fauna

The Hungarian mosquito fauna mainly contains widely distributed Palaearctic and Nearctic species. Revelation of the presently well known fauna is seen on Figure 1. (See in detail in Tóth and Kenyeres, 2012). It can be seen on the increasing dynamics of the detected species number that systematic researches of the Hungarian mosquitoes have been started in the 1930s, related to the elimination of the malaria-endemisms. The most intensive interval of the revelation passed from 1950s to the 1960s. Since the 1970s the known species number of the fauna has been enlarged with just a few species. In the latest decades the detailed examination of the distribution of the species was carried out.

A total of 50 mosquito species have been recorded in Hungary. Distribution maps of the species at the scale of 2.5 km × 2.5 km UTM-quadrates were published by Tóth and Kenyeres (2012), excluding Aedes geminus which has been collected recently by Soltész (2012). The current checklist was compiled according to the list of Snow and Ramsdale (2003).

Culicidae
Subfamily Anophelinae
Genus Anopheles Meigen, 1818
Subgenus Anopheles Meigen, 1818
(1) *Anopheles algeriensis* Theobald, 1903
(2) *Anopheles atroparvus* Thiel, 1927
(3) *Anopheles claviger* (Meigen, 1804)
(4) *Anopheles hyrcanus* (Pallas, 1771)
(5) *Anopheles maculipennis* Meigen, 1818
(6) *Anopheles messeae* Falleroni, 1926
(7) *Anopheles plumbeus* Stephens, 1828
Subfamily Culicinae
Genus Aedes Meigen, 1818
Subgenus Aedes Meigen, 1818
(8) *Aedes cinereus* Meigen, 1818
(9) *Aedes geminus* Peus, 1970

(10) *Aedes rossicus* Dolbeshkin, Goritzkaja & Mitrofanova, 1930
Subgenus Aedimorphus Theobald, 1903
(11) *Aedes vexans* (Meigen, 1830)
Genus Ochlerotatus Lynch-Arribálzaga, 1891
Subgenus Finlaya Theobald, 1903
(12)*Ochlerotatus geniculatus* (Olivier, 1791)
Subgenus Ochlerotatus Lynch-Arribálzaga, 1891
(13) *Ochlerotatus annulipes* (Meigen, 1830)
(14) *Ochlerotatus cantans* (Meigen, 1818)
(15) *Ochlerotatus caspius* (Pallas, 1771)
(16) *Ochlerotatus cataphylla* (Dyar, 1916)
(17) *Ochlerotatus communis* (de Geer, 1776)
(18) *Ochlerotatus detritus* (Haliday, 1833)
(19) *Ochlerotatus dorsalis* (Meigen, 1830)
(20) *Ochlerotatus excrucians* (Walker, 1856)
(21) *Ochlerotatus flavescens* (Müller, 1764)
(22) *Ochlerotatus hungaricus* (Mihályi, 1955)
(23) *Ochlerotatus leucomelas* (Meigen, 1804)
(24) *Ochlerotatus nigrinus* (Eckstein, 1918)
(25) *Ochlerotatus pulcritarsis* (Rondani, 1872)
(26) *Ochlerotatus pullatus* (Coquillett, 1904)
(27) *Ochlerotatus punctor* (Kirby, 1837)
(28) *Ochlerotatus sticticus* (Meigen, 1838)
(29) *Ochlerotatus surcoufi* (Theobald, 1912)
Subgenus Rusticoidus Shevchenko & Prudkina, 1973
(30) *Ochlerotatus refiki* (Medschid, 1928)
(31) *Ochlerotatus rusticus* (Rossi, 1790)
Genus Coquillettidia Dyar, 1905
Subgenus Coquillettidia Dyar, 1905
(32) *Coquillettidia (Coquillettidia) richiardii* (Ficalbi, 1889)
Genus Culex Linnaeus, 1758
Subgenus Barraudius Edwards, 1921
(33) *Culex modestus* Ficalbi, 1890
Subgenus Culex Linnaeus, 1758
(34) *Culex mimeticus* Noé, 1899
(35) *Culex pipiens pipiens* Linnaeus, 1758
Culex pipiens pipiens biotype *molestus* Forskal, 1775
(36) *Culex theileri* Theobald, 1903
(37) *Culex torrentium* Martini, 1925
Subgenus Maillotia Theobald, 1907
(38) *Culex hortensis* Ficalbi, 1890
Subgenus Neoculex Dyar, 1905
(39) *Culex martinii* Medschid, 1930
(40) *Culex territans* Walker, 1856
Genus Culiseta Felt, 1904
Subgenus Allotheobaldia Broelemann, 1919
(41) *Culiseta longiareolata* (Macquart, 1838)
Subgenus Culicella Felt, 1904
(42) *Culiseta fumipennis* (Stephens, 1825)
(43) *Culiseta morsitans* (Theobald, 1901)
(44) *Culiseta ochroptera* (Peus, 1935)
Subgenus Culiseta Felt, 1904
(45) *Culiseta alaskaensis* (Ludlow, 1906)
(46) *Culiseta annulata* (Schrank, 1776)
(47) *Culiseta glaphyroptera* (Schiner, 1864)
(48) *Culiseta subochrea* (Edwards, 1921)
Genus Orthopodomyia Theobald, 1904
(49) *Orthopodomyia pulcripalpis* (Rondani, 1872)
Genus Uranotaenia Lynch-Arribálzaga, 1891
Subgenus Pseudoficalbia Theobald, 1912
(50) *Uranotaenia unguiculata* Edwards, 1913

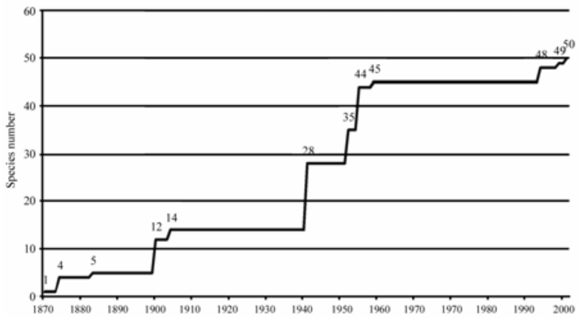

Figure 1 The most intensive interval of the recognition process of the Hungarian mosquito fauna was in the 1950s and 1960s

We examined the frequencies of the species with the use of a summed database of the published imago-, larva and pupa data. In that we synthesized all the quantitative information available in the items of the compilation of "*Bibliography of the Hungarian mosquito research (1832–2011)*" (Kenyeres ed., 2012). For the objective quantities we cancelled the samples of biting females, because the anthropophilous species are overrepresented in that.

It can be seen on Figure 2 that the majority of the collected specimens belong to 5~6 species (*Ochlerotatus annulipes, Culex pipiens pipiens, Aedes vexans, Coquillettidia richiardii, Ochlerotatus*

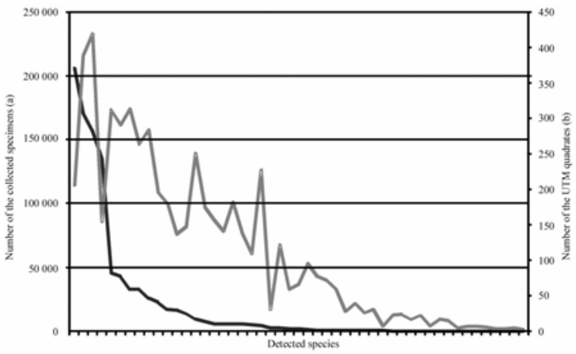

Figure 2 Spatial frequency and frequency in the collected material are often divergent in the Hungarian mosquito fauna (a: The black line; b: The grey line) (based on the published data)

sticticus, Culiseta annulata) [frequencies of the species in different stages and at different sampling methods see in Tóth and Kenyeres (2012)]. We found that those species of which being extremely rare based on their contingent in all the collected specimens are also rare based on the distributional indicators of UTM maps (Figure 2). In other frequency categories sometimes large differences are seen between spatial frequency and frequency in the summed database of the collections. Several species of the Hungarian mosquito fauna are frequent in some parts of the country, but generally are not common or does not occur consistently with high individual number.

With tendential researches and evaluation of the former data we revealed those important habitat-variables of which determine the local occurrences and densities of the species (Kenyeres et al., 2011), further the structure of the larval assemblages (Bauer et al., 2011; Kenyeres et al., 2012) (Figure 3).

The main result of the above mentioned examinations was that larval presence and abundance of the Hungarian mosquito species are determined mainly by the permanent or temporal character of the breeding sites. Almost all the further examined habitat-variables are related to the length of the habitats' water cover. Species abundant in ephemeral water bodies are usually related to clear water, lack of pondweed vegetation and low coverage of the water surface. Then again species abundant in permanent water habitats are usually related to cloudy water, presence of pondweed vegetation and high coverage of the

Figure 3 Local frequencies of the mosquito species are determined mainly by the permanent or temporal character of the breeding sites based on the detected positive relationships

water surface. In connection with several species, e.g. *Culex pipiens pipiens* is very common both in statistical and spatial aspects, we have not found any habitat requirement limiting species density or occurrences.

The most important features of the Hungarian mosquito life-form diversity are seen on Figure 4. 33 from the 50 recorded species belong to three life-form-types: (a) hibernate in egg state, feeding on mammals, univoltine (13 species); (b) hibernate in imago state, feeding on mammals, multivoltine (11 species); (c) hibernate in egg state, feeding on mammals, multivoltine (9 species).

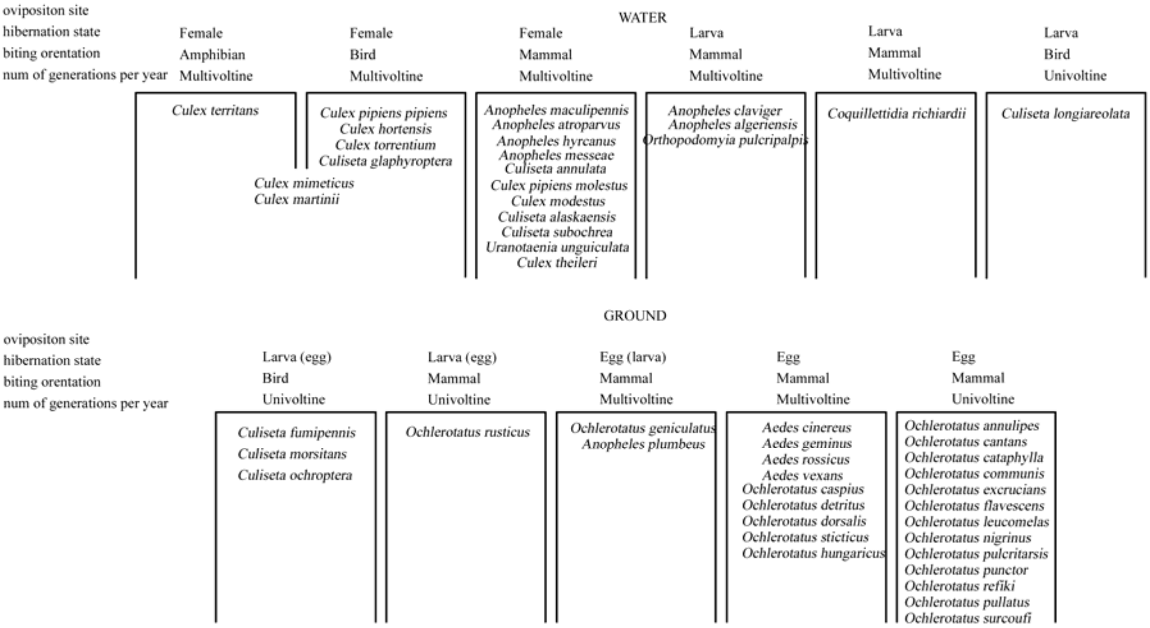

Figure 4 Hungarian mosquito life-form diversity is dominated by three life-form-types

2 Background variables of the diversity of the Hungarian mosquito fauna

The Hungarian mosquito fauna is so species rich in European comparison (Figure 5). It manifests not only in the high species number, but in species richness relatively to the areas of the countries. In comparison the local species numbers projected to 1000 km^2 of the given countries species richness of the Hungarian fauna is overtook just by European Turkey, Slovakia and Croatia.

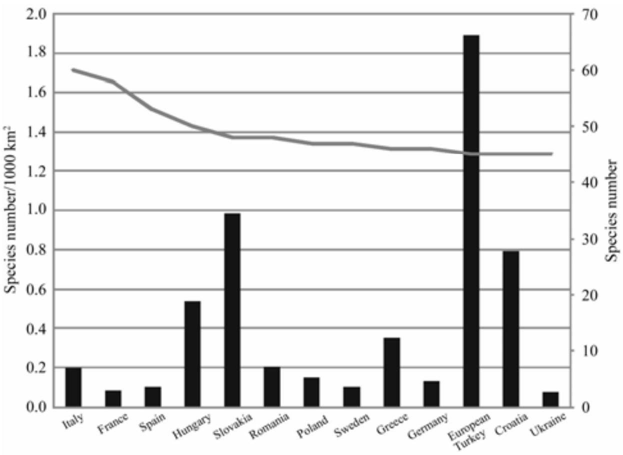

Figure 5 Recorded species numbers (line) and species numbers projected to 1000 km2 (columns) in the European countries characterized by the most rich mosquito faunas

Hydrography, climate and land-use of Hungary are characterized by different requirements and well adapted for habitation by mosquitoes (Tóth and Kenyeres, 2012), so we hypothesized that high species richness of the country originates from the diverse landscape-structure and this phenomenon can also be proved within the country, with comparison of regions characterized by different landscape structure. In several European countries the invasive mosquito species increase the diversity of the local fauna. These species have not been known in Hungary as permanent element of the fauna, but based on Seidel et al (2012) active dispersion of *Aedes japonicus* has reached to Hungary near the Slovenian border.

For testing of our hypothesis we choose regions characterized by well-known local mosquito fauna and different landscape-structure. (A) mountainous regions: Bakony Region (Tóth, 2006), Mátra Region (Tóth, 2009), Mecsek Mts. (Tóth, 2011); (B) lake with natural waterside vegetation: Balaton (Tóth and Sáringer, 2002); (C) natural flooded areas on riversides: interval of Danube River (Kenyeres and Tóth, 2005); (D) artificial and semi-natural flooded areas on riversides: area of Lake Tisza (Tóth et al. unpublished).

With the use of the above cited monographic works we counted the species numbers and the diversity-profiles (Tóthmérész, 1997) of the studied regions.

Habitat-diversities of the regions were determined based on the geographic information of CORINE maps at the landscape scale: cover values and diversity-profiles of the natural habitats and within that cover values and diversity-profiles of the humid habitats. Following diversity indices of the regional mosquito faunas and regional landscape-structures were quantified: dominance diversity, Shannon-diversity, Simpson-diversity, Evenness, Menhinick-index, Margalef-index, Equitability, Fisher alpha-index and Berger-Parker-index. Relations among diversity indices were examined with Pearson's correlation and linear regression analysis (PAST 1.95, Hammer et al., 2001).

Diversity ordering of the regional faunas showed (Figure 6) that diversities of the three mountainous regions (Bakony Region, Mátra Region and Mecsek Mts.) exceed from the studied areas. Further, within these regions the mosquito diversity in the Mátra Region is especially outstanding. Diversities of mosquito faunas occurring around Lake Tisza and Lake Balaton lower than in the mountainous regions, but these two faunas could not ordered related to each other. The flooded area of the Danube River has the lowest mosquito diversity from the studied ones.

Analyses of the life-form diversity of the local mosquito faunas did not show the above mentioned differences. Mosquito life-form diversities of four regions (Bakony Region, Mátra Region, Lake Balaton, Mecsek Mts.) are very similar, they cannot be ordered based on this community parameter. During this examination just Lake Tisza and Danube characterized by flooded areas separated from the other studied sites. Their life-form diversities are low and can be ordered (Lake Tisza >> Danube River).

High diversity of humid habitats of the Mátra Region is unequivocal at all the indices of the diversity profiles. Related to the other regions can be seen that some indices demonstrate higher habitat-diversity of

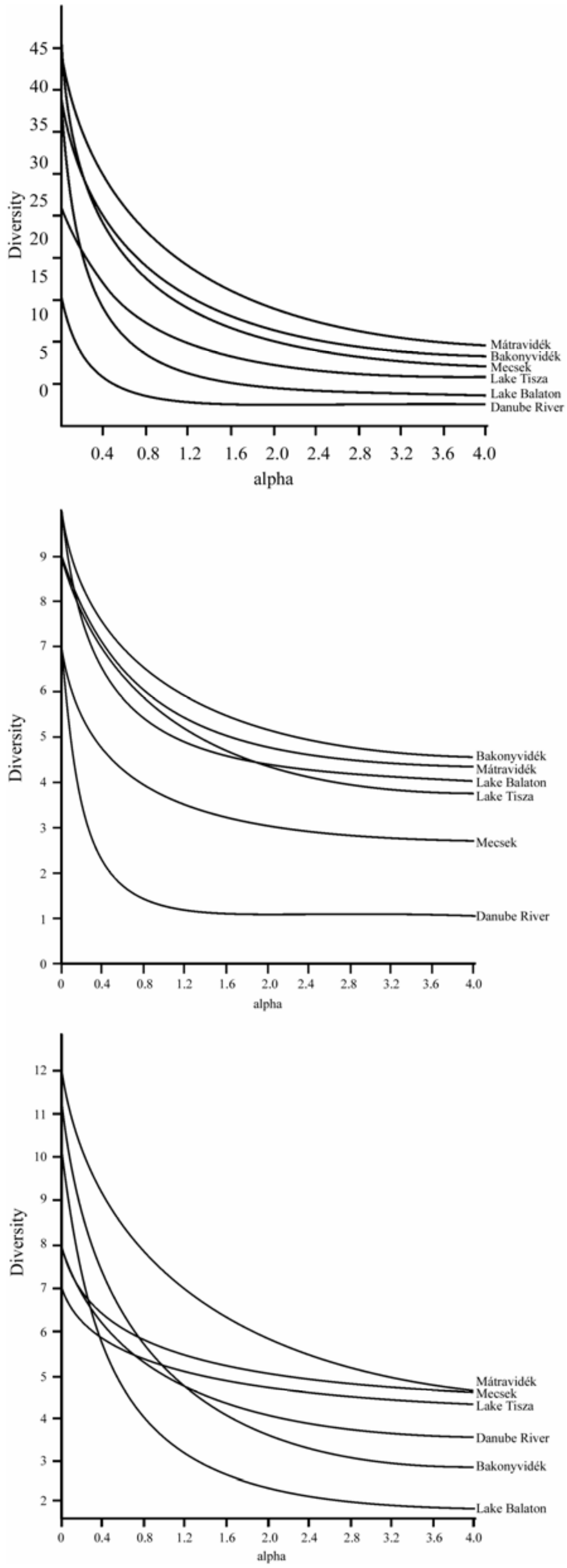

Figure 6 Diversity profiles of the studied regions: mosquito species diversity (top), mosquito life-form diversity (middle) and diversity of humid habitats at landscape scale (bottom)

Bakony Region and Lake Balaton, but others demonstrate that landscape is more diverse in the Mecsek Mts., at Lake Tisza and around Danube River. These differences could be attributed the different sensitivity of the indices to frequency of rare and common habitats.

Pearson's correlation analyses show very strict significant positive relation ($R=0.938$, $p=0.006$) between Menhinick diversity-indices of mosquito fauna and diversity of the humid habitats in the landscape structure. Among other indices we did not reveal relations or revealed not significant relations. In connection with this we have to note that strict significant positive relation was detected at Menhinick diversity-index which is very sensitive to the species richness (Washington, 1984).

Our results show that species richness of the local faunas at the studied scale depends on the diversity of the humid habitats. It was confirmed by the result of the linear regression analysis too (Figure 7).

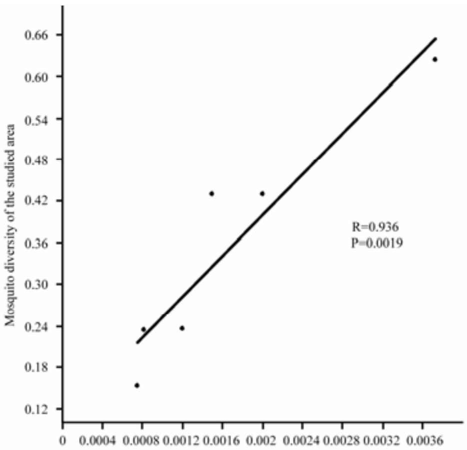

Figure 7 Linear regression analysis of the diversity-indices shows that diversity of the local faunas depends on the diversity of the humid habitats

3 Conclusions

The Hungarian mosquito fauna including 50 species has to consider as a species rich fauna in comparison to the area, macroclimate and geographical location of the country. Although, the cover of the natural and semi-natural habitats is relatively high (31%) in Hungary this species richness is higher than that could be predicted based on climatic and zoogeographical circumstances of the region. Our results show that high diversity of the Hungarian mosquito fauna originated from the fact that relevant geographical range, the Carpathian Basin, is characterized by higher landscape diversity in the humid habitats than the surrounding areas. Take into consideration that Bueno Marí and Jiménez-Peydró (2011) revealed similar relations in Eastern-Spain we could treat examination of λ-, β- and γ-diversity of mosquitoes at large scale as a perspective project.

Author's Contributions

ZK and ST collected and systematized data, KZ performed the statistical analyses and the manuscript. ST read and approved the final manuscript.

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