University of Sopron, Faculty of Forestry

Roth Gyula Doctoral School of Forestry and Game Management

Diversity and Ecology of Forest Ecosystems

Szabolcs Sáfián

The butterfly fauna (Lepidoptera: Papilionoidea) of Liberia

PhD theses

Supervisor: prof. Dr. Ferenc Lakatos

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Introduction and aims of the study

Earth is experiencing the sixth extinction event, which is a result of the cumulated effects of human activities since the dispersal and of *Homo sapiens* through the industrial revolution to the present technological advancement.

To understand the processes and to target the mitigation of human footprint, we urgently need to understand the biological components of the key ecosystems including the 25 identified biodiversity hotpots as entire biomes could disappear before we even begin to understand their function. Although insects account for almost 60% of all described species, knowledge on their communities is extremely limited and their importance has been marginalized until very recently, when the spotlights have been finally directed on the global pollination crisis.

For these reasons, the importance of checklists and to understand species' distribution is also growing rapidly, as they serve as important tools for assessment of biodiversity and risk of extinction, and they contribute to the identification of key ecosystems and other areas of outstanding conservation importance. For these reasons, the importance of checklists and understanding of species distribution is growing rapidly, as they serve as important tools for assessment of biodiversity and risk of extinction and contribute to the identification of key ecosystems and other areas of outstanding conservation importance.

National checklists of any invertebrate groups are scarce in West Africa. National checklist on the butterfly fauna exists only for four countries The Gambia, Guinea-Bissau, Ghana and an older one for Liberia. Recognizing the need, this work targets to support conservation work in the region and to help the better understanding of distribution and biogeography of Liberian and West African butterflies via presenting an updated comprehensive checklist.

1. Liberia encompasses approximately half of the remaining rainforest area in the Upper Guinean forest zone. These forests are predicted to harbour a butterfly diversity, generally richer than the surrounding forest areas.

2. The large and intact lowland forest areas in Liberia and the isolated mountains could still host unrevealed diversity of butterflies which include previously undiscovered and scientifically undescribed species.

3. A considerable proportion of the newly discovered butterfly taxa are expected to be narrowly distributed and thus endemic to the Liberian subregion or are narrowly endemic to a small area within the the subregion.

4. It is hypothesized that the special geographic position and humid macroclimate prevent the influx of masses of species from the savannah belt, and Liberia still maintains a forest butterfly fauna despite utilization of vast areas for agriculture and urban development.

5. All previous hypotheses support the recognition of the Liberian subregion a previously vaguely defined biogeographical sub-unit of the Upper Guinean forest zone.

Material and methods

Literature review

Liberian butterfly records from all published books, papers, scientific reviews and unpublished reports were entered into a database, via a critical review to allow corrections or omission of misidentified species from the checklist, also to update nomenclature.

Field methods and identification

During the extensive fieldwork over the last decade, butterflies were recorded using the following field methods: field observation, photographic documentation and capture using conventional hand-held net. Frugivorous butterflies and those attracted to foul substances were collected using baited net-traps. To a smaller extent, artificial light was

also used to record butterflies and some species were bred from caterpillar stage. Collected specimens were deposited in recognized collections, where beyond identification using museum material and literature, genitalia dissection and identification were also performed, when found necessary.

Databasing of records and editing distribution maps

All raw records with valid date and distribution data were first entered into a Microsoft Excel record sheet, then converted into a MySQL database. The corrected MySQL database was again converted into csv format to be recognised by QGIS 2.4 open source geoinformation analytic program, in which all distribution maps were processed and exported into high resolution images. The following layers were used to display the occurrence maps: NaturalEarth raster (base map), Liberia coloured DEM model (ASTER GDEM v2), 30mx30m grid.

Species accumulation and species richness extrapolation

Species richness and accumulation were estimated with rarefaction, using data from the self-assembled Liberian butterfly database, where dates of publication or collection of old data were available, as well as the more accurate collecting dates for the recent records. The prediction of species richness of butterflies of Liberia was modelled by fitting Michaelis-Menten asymptotic mathematical function to the species accumulation curve.

Ecological (habitat) and biogeographical (distribution) composition

The following ecological groups were used to categorize Liberian butterflies according to their habitat use: Wet forest taxa (WEF), Mesophilous forest taxa (MEF), Dry forest taxa (DRF), All forest taxa (ALF), Upland forest taxa (UPF), Guinea savannah taxa (GUI), Sudan savannah taxa (SUD), Ubiquitous taxa (UBQ), Taxa with special habitat requirements (SPE), Insufficiently known taxa (INS).

All Liberian butterfly butterflies were categorised into the following distribution groups to assess biogeographical patterns and identify endemism: Cosmopolitan taxa (COS), Pan-African taxa (PAN), Guineo-Congolian (equatorial) forest taxa (EQU), West African forest taxa (WAF), Equatorial savannah taxa (EQS), West African savannah taxa (WAS), Upper-Guinean forest zone endemics (UPG), Liberian subregion endemics (LIB), Narrowly endemic taxa (END), Insufficiently know taxa (INS).

Results and discussion

Species richness, faunistic results

As a result of the study the recorded species richness has increased from the previous 475 to 818. Both the species accumulation curve and richness prediction models indicate that the number of recorded species will still increase but not significantly. In a wider context, Liberia harbours approximately 50% of the West African butterfly fauna, and 75% of all forest-dwelling species. The diversity of forest butterflies is also higher in Liberia then in the Ghana, which stretches across three biogeographic subregions (the Ghana subregion, the Volta subregion and the Dahomey Gap), and the area west of Liberia and the surrounding forest areas in eastern Sierra Leone and the Forest Region of Guinea (collectively the Liberian subregion), from Central-Eastern Sierra Leone across Guinea and Guinea-Bissau to Basse Casamance in Southern Senegal (tentatively recognized as the Western transitional subregion).

Taxonomic novelties

23 taxa, 20 species and 3 subspecies recorded in Liberia were found new and undescribed, and the majority of them were described during the present study, others still in the process of description. The complete list of taxa is as follows in taxonomic order: *Eagris tetrastigma lomana* Belcastro & Sáfián, 2020; *Andronymus fenestra* Belcastro & Sáfián

2019; *Gorgyra ziama* Belcastro & Sáfián, 2020; *Mesoxantha liberiana* sp. n. (manuscript name); *Telcninia pseudepaea ziama* Belcastro, Boireau & Sáfián, 2020; *Aslauga larseni* Sáfián, 2015; *Parasiomera alfa* Sáfián, 2015; *Liptena neiltennanti* Sáfián, 2021; *Micropentila* cf. *brunnea* (Kirby, 1887); *Cephetola praecox* Sáfián, 2021; *Cephetola wologizi* Sáfián, 2021; *Cephetola wingae* Sáfián, 2015; *Geritola pacifica* Sáfián & Libert, 2015; *Stempfferia katikae* Sáfián, 2015; *Stempfferia michelliberti* Sáfián, Warren-Gash & Belcastro, 2021; *Aphnaeus mirabilis* Sáfián & Collins, 2013; *Aphnaeus nimbaensis* Sáfián & Libert, 2013; *Iolaus jadwigae* Sáfián, 2017; *Iolaus liberiana* Sáfián, 2017; *Cupidesthes* cf. *robusta* Aurivillius, 1895; *Triclema melambrotus liberiana* ssp. n. (manuscript name); *Pilodeudorix mano* Sáfián, 2015; *Pilodeudorix putu* Sáfián, 2015; *Pilodeudorix intermedia* Sáfián, 2015.

Ecological composition

As Liberia is situated entirely inside the Upper Guinean forest zone, it is not coincidence that 86% of all species occurring in Liberia are associated with forest habitats (705 species) and only 13% (103 species) are associated with open habitats such as savannah, farmland and degraded areas. The high proportion of the butterfly fauna associated with wetter forest types (WEF) and in contrast the low proportion of taxa associated with dry forest (DRF) (36% and 3%) indicate both wetter ecological conditions and intactness of the forest ecosystem, as both groups contain taxa usually of narrow ecological tolerance. Mesophilous forest species (MEF) (24%, 199 species) and species distributed in all forest types (ALF) (19%, 155 species) are generally widely distributed and common and have variable tolerance for habitat degradation. The upland forest species (UPF) form a special group of taxa, as they are usually of restricted range or even narrowly endemic in West Africa. In Liberia their representation is significant, altogether 3.5% and 29 taxa are listed in the group. Of the savannah-dwelling species the wetter Guinea savannah species (GUI) dominate in Liberia with 7.5% (61 species) of all species recorded, while the dry Sudan savannah species are very poorly represented (0.4%, 4 species). Even these are usually common

species with good dispersal abilities or migratory tendencies. Ubiquitous species represent 4% of the Liberian butterfly fauna with taxa distributed across West Africa. Only 3 species are found associated with special habitats (SPE), mainly wetlands and 10 species are insufficiently known (INS) to be included in any of the ecological groups.

Endemism

Upper Guinean forest zone endemics are represented by rather widely distributed and often common taxa occurring between the Dahomey Gap and the outlier forests of Basse Casamance in Southern Senegal, such as *Cymothoe mabillei*, *Euphaedra eupalus*, *Larinopoda eurema*, *Falcuna leonensis,* although some of them are very rare, and known from sporadic records like *Bebearia ashantina*, *Pseudaletis richardi*. Liberian subregion endemic taxa are predominantly limited to the wet forest area between the Sassandra River in Western Ivory Coast and South-Central Sierra Leone, including the Forest Region of Guinea. Only a few of these are commoner and found regularly across the subregion: *Pseudopontia gola*, *Euriphene veronica* and *Ceratrichia crowleyi*, the majority of the species are known from a few records (e.g. *Gorgyra ziama*, *Andronymus fenestra*, *Euriphene lomaensis*) and some are definitely very local and rare (e.g. *Parasiomera alfa*, *Geritola pacifica*). A few species have disjunct occurrences in the wet forest area along the southern border between Ghana and Ivory Coast, as a secondary centre of distribution, and in other outpost occurrences in mountainous areas in Ghana and Guinea.

In Liberia, all narrowly endemic butterfly taxa are restricted to three mountainous areas: the Putu Range, the Nimba Mountains and the Wologizi Mountains. They are either pre-montane or are associated with the unique upland forest habitat. Currently, *Liptena neiltennanti* sp. n., *Cephetola praecox* sp. n. and *Iolaus jadwigae* are known only from the Putu Range, while *Pilodeudorix putu* and *P. intermedia* are known from Putu and the Nimba Mountains, all from upland forest. *Aslauga larseni* was, so far, found exclusively in the Nimba Mountains in upland habitat, while *Cephetola wologizi* sp. n. is known from two specimens collected

in the Wologizi Mountains, again, in upland forest. Two species, *Hypolimnas aubergeri* and *Euphaedra aubergeri* are pre-montane rather than upland specialists, they were also found in other isolated mountainous areas in the Guinea Highlands outside of Liberia.

Biogeographical (distribution) pattern

The biogeographical (distribution) pattern of butterflies in Liberia was formed mainly by the history of climate in correspondence with the available habitat types, but also on the dispersal and colonisation ability of species and their susceptibility to speciation due to changing environment.

Considering distribution patterns, the butterfly species could be categorized into the following groups: Cosmopolitan (COS) species, distributed over multiple continents represent only 1% (8 species) of the Liberian butterfly fauna. The proportion of Pan-African species distributed across sub-Saharan Africa are significantly higher (7.5%, 60 species) but still relatively low, they usually inhabit more open habitat types as forest is not distributed across the continent. Not surprisingly, taxa of Guineo-Congolian or equatorial forest (EQU) distribution take up 45% of all species (372 taxa), followed by West African forest species (WAF) with 125 taxa (15%) and Upper Guinean forest zone (UPG) endemic taxa (15.6%, 128 species). Equatorial savannah (EQS) species represent 3.6%, 26 species, while West African savannah (WAS) species are slightly over 1%, 12 species. Biogeographically the most important groups are those encompass restricted-range species, such as Liberian subregion endemics (LIB) with an outstanding proportion of 7% and 58 taxa, and the group of narrowly endemic (END) ones which represent 2.69% (22 taxa) of the fauna. The high proportion of endemism in the region supports the forest refuge hypotheses for the area of Liberia as highlighted below.

Re-definition of the Liberia subregion

Both the diversity patterns and the outstanding number of endemic taxa support the recognition of the Liberian subregion (previously referred to as Liberia forest region). In encompasses entire Liberia and the lowland forest area in Western Ivory Coast to the Sassandra River in the east, the eastern mountainous areas of the Guinea Highlands in north-western Ivory Coast and in the Forest Region of Guinea including the lowland forest areas between them, In Sierra Leone, the northern edge of the subregion is drawn north of the Loma Mountains, the Tonkolili Forest Reserve and the Bumbuna area before the boundary line turns southward to the coast passing just west of the Western Peninsular Mountains near Freetown.

A secondary centre of distribution of butterfly taxa with distribution centred on Liberia disjunct from the Liberian subregion was identified along the southern border of Ghana and Ivory Coast where locally higher precipitation allowed the formation of wet evergreen lowland forest. A number of Liberian subregion endemics were recorded from this area: e.g. *Euriphene veronica*, *E. leonis*, *Euptera dorothea warrengashi*, *Ceratrichia crowleyi* but other species associated with upland, pre-montane and submontane habitats are almost certainly absent from this area.

Further outpost distribution areas of butterflies with distribution centred on Liberia are identified further east in Ghana and also further west in Guinea. The isolated Atewa Range in Ghana hosts a small area of unique upland evergreen forest, with higher butterfly diversity and recognized endemism. Two Liberian subregion endemics, *Pseudacraea hostilia* and *Andronymus fenestra* are known to occur in isolation in the Atewa Range. Although the massif of Fouta Djallon and the isolated mountains near the coast in Guinea are largely covered by savannah habitats on the plateaus, the stretches of riverine forests in the gullies and the patches of upland and submontane forest still maintain a less diverse forest butterfly fauna. They also harbour at least two Guinea Highland endemic (in a broader context) species with upland affinities: *Uranothauma belcastroi* and *Mylothris boireaui*.

From literature review it appears that the Liberian subregion largely overlaps with two of the postulated Pleistocene forest refuge areas: the Liberian refuge area and the Cape Palmas refuge area, based largely on analysis of various plant groups. More interestingly, the secondary centre of distribution of Liberian subregion butterflies in southern Ghana and Ivory Coast clearly overlaps with the Cape Three Points refuge area, while Atewa in Ghana and the Fouta Djallon and the southern mountains in Guinea were also recognized as microrefugia for other animal groups.

Theses

1. Review of literature data and extensive field surveys resulted in 818 butterfly species positively recorded and identified from Liberia, an increment of 72% since the publication of the latest comprehensive fauna work. Both the Michelis-Menten model and the known butterfly records near the borders of Liberia (eastern Sierra Leone, the Forest Region of Guinea and western Ivory Coast) indicate even higher butterfly diversity in the country. Although Ghana has significantly higher richness of butterflies (estimated to exceed 950 species), approximately 150 are associated exclusively with Guinea and Sudan savannah habitats, the majority of them are not expected to occur in Liberia. It is also important to emphasize that Ghana stretches across three biogeographical subregions; the Volta subregion or Togo Mountains, the Dahomey Gap and the Ghana subregion, and in the extreme southwest and in two small upland rainforest areas disjunct populations of a few Liberian subregion endemic species are also found. According to extensive faunistic studies a single intact forest area in Ghana would harbour approximately 500-650 species. It should be similar to the diversity in the poorly documented eastern Ivory Coast, derived from data originate from forests on the Ghana-Ivory Coast border. The recent field studies in Liberia and in the Liberian subregion, just beyond the Liberian border revealed higher butterfly diversity in single forest areas, reaching approximately 700 species. Further west in Guinea, Guinea-Bissau and southern Senegal the diversity of forest butterflies drops drastically. These fragmented outlier

forests of the yet undefined Western subregion are strongly impoverished in butterflies, leaving Liberia to be the ultimate hotspot of diversity of forest butterflies in the Upper Guinean forest zone.

2. The unrevealed diversity of butterflies in Liberia and in the broader context of Liberian subregion proved significantly higher than hypothesized. Altogether, twenty-three undescribed taxa – almost 3% of the Liberian fauna – were new discoveries, including twenty species and three subspecies.

2a. The majority of new taxa found during the study remained unrevealed until now for the lack of field research in Liberia, as they are generally easily recognizable species and none of them were collected previously and were found in museum collections. The several of these species appear to have no close relatives in West Africa and they probably evolved in genuine allopatry, often with a distance over a couple of thousand kilometres between the Liberian species and its supposedly closest relative. These taxa include: *Geritola pacifica*, *Cephetola wologizi*, *Aphnaeus nimbaensis*, *A. mirabilis*, *Pilodeudorix mano*,

2b. A significant proportion of new taxa could be considered as cryptic diversity, as several of them are almost identical or generally very similar to their respective closest relatives and recognition of their uniqueness required examination of longer series of comparative material across their distribution, also dissection and examination of genitalia. Quite a few of these taxa belong to species-groups that consist of several similar species or a single species with multiple subspecies, and beyond the morpho-taxonomic comparison, understanding of their biogeographic pattern also played an important role in clarification of their taxonomic status. These taxa include *Parasiomera alfa*, *Liptena neiltennanti*, *Mesoxantha liberiana* and *Eagris tetrastigma lomana*. In one case a single, Upper Guinean endemic species, *Pilodeudorix aurivilliusi* seems to have evolved further, resulting in two additional species in the Liberian subregion, *P. putu* and *P. intermedia*. They both are known only from a

few upland localities where all three are genuinely sympatric, ruling out subspecific relationship.

2c. Further undescribed taxa are still expected to occur in the region as undescribed species and subspecies were also found in the Forest Region of Guinea (Guinée Forestiére) near the Liberian border: *Apallaga klaudiae* Sáfián, Boireau & Belcastro, 2020, *Junonia agnesberenyiae* Sáfián, 2019 and *Neurellipes helpsi* ssp.n.

3. According to the information available, all newly described taxa are considered to be of restricted range to variable extent and thus endemic to a biogeographically well-defined area in West Africa. Alongside groups of previously recognized taxa, they could be categorized in three groups of endemics according to their distribution range.

Upper Guinean endemics: 128 taxa were recognized as being restricted to the forest zone between south-western Senegal to Ghana or the Volta subregion in eastern Ghana and western Togo. A considerable proportion of these taxa are rather widespread and common within the Upper Guinean forest zone, and some have wide ecological tolerance in habitat occupancy, also for disturbance. For this reason, it is not surprising that among the newly discovered taxa only one is considered as an Upper Guinean forest zone endemic: *Iridana kollariki* Sáfián, 2014, which was first found in Ghana and was only later discovered in Liberia. The Ghanaian locality does not fit in the unique upland localities, where disjunct, probably relict populations of a few species, considered endemic to the Liberian subregion exist.

Liberian subregion endemics: 58 taxa are restricted to a rather small, but well-defined forest area between eastern/central Sierra Leone and western Ivory Coast, they could also occur sporadically in the Forest Region of Guinea. This area receives the highest annual precipitation in West Africa, west of the Gulf of Guinea Highlands, influenced by the extensive mountainous areas of the Guinea Highlands, and is also recognised as a hotspot for endemism for various plant and animal

groups. Many of the Liberian subregion endemic butterflies are found in wet to hyperwet lowland forests and they are widely distributed within their range but they usually have limited ability to adapt to changes of ecological factors or habitat disturbance, or they might utilize plant species also restricted to this subregion. Only a few have slightly broader distribution, occurring also in limited areas of south-western, western Ghana, a postulated forest refuge area. Two species were found in one of the two unique upland localities in Ghana (Atewa Range) in correspondence to locally higher precipitation. A significant proportion of the newly discovered taxa could be considered as endemic to the Liberian subregion, distributed rather widely in lowland and occasionally also in upland forests within the subregion. *Parasiomera alfa*, *Geritola pacifica* were, so far found exclusively in Liberia, whereas beyond their Liberian subregion records *Mesoxantha liberiana* and *Andronymus fenestra* were found also in Ghana; the former one in the southwestern wet forest area, while the latter in the upland forests of Atewa Range.

Narrowly endemic taxa: 22 narrowly endemic taxa were identified from three mountainous areas in Liberia: the Nimba Mountains (also referred to as Nimba mountain refugium), which was for a long time recognised for its high rate of endemism and the postulated Liberian forest refugia is also centred on the Nimba Mountains. Several butterfly taxa are known to occur only in the Nimba Mountains, including *Vanessula milca angustifascia*, *Euphaedra sarcoptera ferrea*, *Aslauga larseni*. However, recent field-studies revealed that some taxa previously believed to be Nimba endemics also occur in the upland forest zone of the other Liberian higher mountain range, the Wologizi Mountains, and these taxa should occur also in mountainous areas of the Guinea Highlands. These are still considered as narrowly endemic as their distribution within the highlands are probably strictly limited by various ecological factors (e.g. altitude, habitat, food plant). Among others, *Bettonula bettoni nimba*, *Euphaedra aubergeri*, *Cephetola wingae* and *Aphnaeus nimbaensis* were recorded from both the Nimba and Wologizi Mountains, while *Cephetola wologizi* was found exclusively in the upland forests of Wologizi.

The other, quite different mountainous area is the Putu Range, which is a lower mountain range situated in eastern Liberian in complete isolation from all other mountains in the region. It faces the south-westerly moist air of maritime origin, causing rather evenly distributed higher precipitation in the vicinity of the mountain range. These local ecological conditions could have allowed the Putu Range to serve as a microrefugia during the recent drier (glacial) periods, which is well supported by the endemic taxa and local higher butterfly diversity present. *Liptena neiltennanti*, *Cephetola praecox* and *Iolaus jadwigae* were found exclusively in Putu and they could prove narrowly endemic to this small mountainous area inside the hyperwet forest zone. Other species with upland affinities also occur in the lower section of the Nimba mountain range and on the isolated lower mountains of West Nimba. Both *Pilodeudorix putu* and *Pilodeudorix intermedia* first recorded from the Putu Range were also found in upland forests in the Nimba.

4. During the analysis of the ecological composition of the butterfly fauna 86% of all butterfly species were found associated with forest habitats, only 8% are savannah-dwelling species and 4% are ubiquitous. The proportion of species associated with wetter types of forest is very high (over 35%), which is a good indication of intact forest areas in Liberia, but it also indicates that Liberian subregion is generally wetter than the rest of West Africa west of the Dahomey Gap. It is also supported by the low proportion of dry forest elements (3%). Although many of the Guinea savannah species are good colonisers, their proportion still remain relatively low (7%), and only the commoner species of good dispersal abilities and higher tolerance for habitat degradation are present in Liberia. The Sudan savannah elements are almost completely missing from Liberia, their proportion is only 0.5%, and only strong-flying species with migratory tendencies were recorded. Ubiquitous species represent only 4% of the butterfly fauna, however the same widely distributed species usually colonise forests all over West Africa, making the number of ubiquitous species recorded from a single area rather constant.

The intactness of the butterfly fauna is also reflected in the distribution patterns of the species. Over 45% of all taxa inhabit the forest zone from south-western Senegal across the Congo Basin to the Albertine Rift or even beyond (Guineo-Congolian or Equatorial forest species). In addition to the Guineo-Congolian forest taxa, 15% of the fauna is distributed in West Africa's forests east of the Sanaga River in Cameroon. Over 25% of forest dwellers are of restricted range: 15% of them are distributed in the Upper Guinean forest zone, while 7% is found only in the Liberian subregion. More than 2% is narrowly endemic to the upland forest of the mountainous areas of the Nimba and Wologizi Mountains and the Putu Range. Only a very small proportion of the fauna is distributed also beyond Africa (cosmopolitan species) (<1%), and only 7.5% is distributed across the continent (pan-African taxa), inhabiting both open and forest habitats. Taxa distributed in savannah regions are generally underrepresented in the butterfly fauna. Only 3% are widely distributed in a relatively narrow savannah belt that follows the Guineo-Congolian forest zone, while only 1% is distributed in the savannah areas across West Africa.

5. The Liberian subregion appears to be a discrete biogeographical subunit within the Upper Guinean forest zone as indicated by both the diversity patters and the outstandingly high number of endemic/restricted-range species.

5a. The distribution patterns of the Liberian subregion centred species identify a main centre of distribution, which encompasses the lowland forests of Liberia, also those in western Ivory Coast to the Sassandra River in the east, a large proportion of southern Sierra Leone in the west, also major isolated mountainous areas in north-central Sierra Leone, northern Liberia, in the Forest Region of Guinea and also in north-western Ivory Coast.

5b. A large costal forest area originally covered by wet evergreen forest on the Ivory Coast-Ghana border shows strong affinities to the Liberian subregion in precipitation, vegetation and in the presence of several

Liberian subregion centred butterfly species. From the current knowledge of the butterfly fauna, it is not possible to assess whether or not this area should be considered as an integral part of the Liberian subregion, but the upland endemic elements of the subregion are almost certainly missing from this disjunct, essentially lowland area. The above defined Liberian subregion and this disjunct area effectively cover the three postulated Upper Guinea Forest Refugia (1. Liberian refuge area, 2. Cape Palmas refuge area, 3. Cape Three Points refuge area) as was identified for various plant groups.

5c. The Atewa Range, a small isolated mountainous area in the Eastern Region of Ghana has strongly disjunct records of a few Liberian subregion centred butterfly. Atewa is one of the two unique upland forest localities in Ghana, it shows exceptional butterfly diversity with the presence of an endemic butterfly species. Although Atewa was not recognized as part of forest refugia, it was recently identified as a microrefugium for leaf-litter frogs, which corresponds well with butterfly data. Despite the affinities, the Atewa Range could not be recognized as part of the Liberian subregion but is an isolated relict outpost of Liberian endemic fauna due to its unique ecological conditions.

5d. Although geographically they are considered as part of the Guinea Highlands, the massive Fouta Djallon highlands area and other isolated mountainous area in southern Guinea are not integral part of the Liberian subregion; they rather serve as minor outposts of a few Liberian subregion centred butterfly species due to their mountainous properties similar to those in their main distribution area, but these mountainous areas show already a transition towards the yet undefined 'Western transition subregion' with their own endemics and significantly lower diversity of forest butterflies compared to the above defined Liberian subregion.

Publications directly related to the thesis (with impact factor)

Mitter, K.T., Larsen, T.B., de Prins, W., de Prins, J., Collins, S.C., vande Weghe, G., Sáfián, Sz., Zakharov, V.E., Hawthorne, D.J., Kawahara, A.Y. & Regier, J.C. (2011). The butterfly subfamily Pseudopontiinae is not monobasic: marked genetic diversity and morphology reveal three new species of *Pseudopontia* (Lepidoptera: Pieridae). *Systematic Entomology*. http://dx.doi.org/10.1111/j.1365-3113.2010.00. **Q1 – IF: 2,943**

Sáfián, Sz., Libert, M. & Collins, S.C. (2013): Two new *Aphnaeus* (Lepidoptera: Lycaenidae: Theclinae) species from Liberia. *Zootaxa* 3718(2):193-199. http://dx.doi.org/10.11646/zootaxa.3718.2.7. **Q3 – IF: 1,060**

Pyrcz, T.W., Warren-Gash, H., Lorenc-Brudecka, J., Knoop, D., Oremans, P. & Sáfián, Sz. (2013). Taxonomy and distribution pattern of the African rain forest butterfly genus *Euphaedra* Hübner sensu stricto with the description of three new subspecies of *Euphaedra cyparissa* (Cramer) and one of *E. sarcoptera* (Butler) (Lepidoptera, Nymphalidae, Limenitidinae, Adoliadini). *Zookeys* (298)1-37. http://dx.doi.org/10.3897/zookeys.298.4894. **Q2 – IF: 0,933**

Sáfián, Sz. (2013). Observation of hill-topping behaviour by the Giant African Swallowtail - *Papilio antimachus* Drury, 1782 and other recent records from Liberia (West Africa) (Lepidoptera: Papilionidae). *Shilap Revista de Lepidopterología.* 41(163):323-329. **Q3 – IF: 0,304**

Sáfián, Sz. (2015). Behaviour and development of *Pseudopontia gola* Sáfián & Mitter, 2011 (Lepidoptera: Pieridae). *Shilap Revista de Lepidopterología.* 43(169):85-89. **Q3 – IF: 0,408**

Sáfián, Sz. & Collins, S.C. (2015). Establishment of a new genus for *Eresiomera paradoxa* (Schultze, 1917) and related taxa (Lepidoptera:

Lycaenidae) with description of two new species. *Zootaxa.* 4018(1):124-136. http://dx.doi.org/10.11646/zootaxa.4018.1.7. **Q1 – IF: 0,991**

Sáfián, Sz., Collins, S.C. & Libert, M. (2015). Two new species in the genus *Geritola* Libert, 1999 (Lepidoptera: Lycaenidae, Epitolini). *Zootaxa.* 3931(2):286–292. **Q1 – IF: 0,991**

Sáfián, Sz., Belcastro, C. & Tropek, R. (2019). Two new species in the genus *Andronymus* Holland, 1896 (Lepidoptera, Hesperiidae). *Zootaxa.* 4624(1):108-
120. http://dx.doi.org/https://doi.org/10.11646/zootaxa.4624.1.7. **Q2 – IF: 0,990**

Sáfián, Sz., Collins, S.C., Belcastro, C., Brattström, O. & Tropek, R. (2019). Description of previously unknown females of three *Euriphene* Boisduval, 1847 species and the unknown male of *Bebearia inepta* Hecq, 2001 from Western Africa, with notes on their taxonomy, bionomy and distribution (Lepidoptera: Nymphalidae, Limenitidinae). *Shilap Revista de Lepidopterologia.* 47(188):581-591. **Q4 – IF: 0,350**

Pyrcz, T.W., Collins, S.C., Zubek, A., Wacławik, B., Sáfián, Sz., Bąkowski, M. & Florczyk, K. (2020). Previously unrecognized diversity of Afrotropical Melanitini butterflies (Nymphalidae, Satyrinae): doubling the number of species and genera. *Arthropod systematics and phylogeny.* **Q2 – IF: 1,175** (2019)

Sáfián, Sz. (2020). Description of the previously unknown sexes in four West African Lycaenidae (Lepidoptera) with new data on their distribution. *Zootaxa*. **Q2 – IF: 0,990**

Total IF: 11,135

Publications directly related to the thesis (without impact factor)

Sáfián, Sz. (2014). Uncovering Liberia's butterfly diversity. Poster Presentation. Butterfly Conservation's Seventh International Symposium.

Sáfián, Sz. (2015). *Aslauga larseni* (Lycaenidae: Miletinae: Liphyrini), a unique new species from the Nimba Mountains, Liberia. *Metamorphosis.* 26:27-30.

Sáfián, Sz. (2015). Two new Epitolini from Liberia in the genera *Stempfferia* Jackson, 1962 and *Cephetola* Libert, 1999 (Lepidoptera: Lycaenidae). *Metamorphosis.* 26:12-19.

Sáfián, Sz. (2015). Observations on the little-known *Geritola frankdaveyi* Libert, 1999 (Lepidoptera: Lycaenidae: Epitolini). *Metamorphosis.* 26:20-24.

Sáfián, Sz. & Collins, S.C. (2014). A new *Iridana* Aurivillius, 1920 and a new *Teratoneura* Dudgeon, 1909 (Lepidoptera: Lycaenidae) from tropical Africa. *Metamorphosis.* 25:90-96.

Sáfián, Sz. & Takano, H. (2019). *Hypolimnas aubergeri* Hecq, 1987 (Nymphalidae, Nymphalinae) a little-known West African butterfly. *Metamorphosis*. 30:14–18.

Sáfián, Sz., Belcastro, C., Boireau, P. & Collins, S.C. (2020). New taxa of skipper butterflies (Lepidoptera, Hesperiidae) from tropical Africa. *Metamorphosis.* 31(1):56-71.

Sáfián, Sz., Coache, A. & Rainon, B. (2020). New data on the distribution of *Iridana agneshorvathae* Collins, Larsen & Sáfián, 2008 with description of the previously unknown female (Lepidoptera, Lycaenidae, Poritiinae). *Faunitaxys.* 8(3):1-3.

Sáfián, Sz., Collins, S.C. & Libert, M. (2015). Descriptions of seven new *Pilodeudorix* Druce, 1891 from equatorial Africa (Lepidoptera: Lycaenidae: Theclinae). *Metamorphosis.* 26:62-78.

Sáfián, Sz., Koïvogui, S., Simonics, G. & Florczyk, K.J. (2020). Butterfly diversity (Lepidoptera: Papilionoidea) in the Ziama Massif in Guinea and the adjacent Wonegizi and Wologizi Mountains in Liberia (West Africa): A transboundary conservation approach *Metamorphosis.* 31(1):104-128.

Sáfián, Sz., Pyrcz, T., Boireau, P. & Belcastro, C. (2020). A new subspecies of *Telchinia* Hübner, [1819] (Lepidoptera: Nymphalidae: Heliconiinae) from West Africa. *Metamorphosis.* 31:45-48.