The Bio-Geographical Regions Division of Global Terrestrial Animal by Multivariate Similarity Clustering Analysis Method

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Abstract

A novel multivariate similarity clustering analysis (MSCA) approach was used to estimate a biogeographical division scheme for the global terrestrial fauna and was compared against other widely used clustering algorithms. The faunal dataset included almost all terrestrial and freshwater fauna, a total of 4631 families, 141,814 genera, and 1,334,834 species. Our findings demonstrated that suitable results were only obtained with the MSCA method, which was associated with distinct hierarchies, reasonable structuring, and furthermore, conformed to biogeographical criteria. A total of seven kingdoms and 20 sub-kingdoms were identified. We discovered that the clustering results for the higher and lower animals did not differ significantly, leading us to consider that the analysis result is convincing as the first zoogeographical division scheme for global all terrestrial animals.

Keywords

Global Animal, Multivariate Similarity Clustering Analysis, Biogeography, Regionalization

1. Introduction

Biodiversity is important to humankind, and the significance of its protection is well recognized by both scholars and governments [1]. Of all the measures for managing and protecting biodiversity, biogeography constitutes a basic, but very useful, tool [2] [3]. The discipline of biogeography originated in 1761 when it was introduced by the French naturalist Georges Buffon [4].
ers were not concerned with the ecological associations of faunal distributions, but were more interested in defining areas that are characterized by certain animals. Based on this, six biogeographic regions corresponding to continents were defined [5] [6]. In 1858, the English ornithologist Philip Sclater defined six zoological regions (Aethiopian, Australasian, Indian, Palaeartic, Nearctic, and Neotropical) that are still in use today [7]. In 1876, the British zoologist Alfred Russel Wallace adopted Sclater’s scheme and, using marsupial distributions, defined the “Wallace line”; a hypothetical line that intersects Indonesia, between Kalimantan and Sulawesi, separating the Oriental (Indian) region and the Australian region [8]. His seminal work, the geographical distribution of animals, later became the foundation of modern biogeography [9], and, despite some minor revisions [10], the original map from this publication is still in use today [11].

The exploration of biogeography has continued into the 21st century. In addition to the lengthy debates regarding the rationality of the “Wallace line” [12] [13] [14] [15], the development of quantitative analytical methods for determining and refining zoogeographical regions has been central to biogeographic research [16]-[26]. There has been considerable focus on zoogeographic division schemes in the last few decades, and a variety of schemes based on different methods have been proposed between 7 - 14 divisions [27]-[42]. Being faced with numerous and disorderly results, Morrone J.J. wonders that bio-geographical regionalization is a spectre haunting biogeography [43]. Unfortunately, there are three significant issues with these proposals.

Firstly, while the necessity for quantitative methods in biogeographic division schemes has been recognized, systematic comparisons of different similarity coefficient formulas and clustering algorithms are lacking. Additionally, some similarity coefficient formulas are only accurate under defined conditions, and thus their use is restricted. Secondly, researchers have used the grid method to define basic geographic units, which are typically generated using latitude and longitude coordinates or geographical distance. Although this method is acceptable, species distribution records, which have been collected and accumulated long-term by taxonomists, are not associated with grid method. The variations in the collection degrees (such as the frequency, timing, and depth) between each grid could result in discrepancies, thereby influencing the model estimation. The grid cell strategy is thus best suited to medium-scale field investigations, but is not appropriate for global-scale clustering analyses. Thirdly, there has been greater focus on higher animals, such as vertebrates, despite the fact that they only represent a small percentage of the global fauna (4% of species, 5% of genera). Lower animals should also be included in biogeographical research. Considering the concerns outlined above, the aim of this study was to develop a division scheme for the global terrestrial fauna based on a comprehensive analytical quantitative framework. To achieve this, we implemented a novel approach based on multivariate similarity clustering analysis (MSCA) combined with the similarity gen-
eral formula (SGF). This method was validated by comparison with widely used clustering algorithms and existing division schemes.

2. Material and Method

2.1. Global Terrestrial Animal Species

The materials used in this study originated primarily from three sources: catalogs, checklists, or taxonomic monographs on global or regional fauna [44]-[66]; biodiversity materials obtained from biodiversity research institutions or websites [67]-[92]; and new species or new distribution publications by taxonomists [93]-[110]. Excluding deep marine species and fossil species, a total of 141,814 genera, and 1,334,834 species of fauna were included (Table 1). The number of genera is about 70% of total number of global animal genera, and number of species is about 75% of total number of global animal species. To maximize the utilization of the above materials and to improve the clarity of the analysis results, we selected to use genus as basic biological units (BBUs).

Table 1. Terrestrial animal of the World.

| Grade  | Phylum                  | Class | Order | Family | Genus | Species |
|--------|-------------------------|-------|-------|--------|-------|---------|
| Higher | 1. Chordata             | 5     | 77    | 613    | 6890  | 48,881  |
| Lower  | 1. Acanthocephala       | 4     | 10    | 25     | 153   | 1406    |
| Lower  | 2. Annelida             | 2     | 18    | 145    | 2105  | 16,602  |
| Lower  | 3. Arthropoda           | 11    | 83    | 2195   | 120,397| 1,167,110|
| Lower  | 4. Brachiopoda          | 5     | 19    | 167    | 460   | 3510    |
| Lower  | 5. Bryozoa              | 3     | 7     | 229    | 987   | 9473    |
| Lower  | 6. Cnidaria             | 3     | 5     | 22     | 63    | 491     |
| Lower  | 7. Gastrotricha         | 2     | 17    | 66     | 911   |         |
| Lower  | 8. Kamptozoa            | 4     | 14    | 14     | 210   |         |
| Lower  | 9. Micrognathozoa       | 1     | 1     | 1      | 1     |         |
| Lower  | 10. Mollusca            | 7     | 41    | 361    | 3372  | 30,388  |
| Lower  | 11. Nematoda            | 2     | 14    | 180    | 1982  | 16,302  |
| Lower  | 12. Nematomorpha        | 2     | 2     | 3      | 22    | 620     |
| Lower  | 13. Nemertea            | 3     | 3     | 42     | 305   | 1423    |
| Lower  | 14. Onychophora         | 1     | 1     | 2      | 52    | 175     |
| Lower  | 15. Phylepheliomorph    | 4     | 41    | 423    | 3894  | 24,894  |
| Lower  | 16. Porifera            | 4     | 32    | 146    | 786   | 9994    |
| Lower  | 17. Rotifera            | 2     | 5     | 15     | 50    | 656     |
| Lower  | 18. Tardigrada          | 3     | 5     | 17     | 118   | 1312    |
| Lower  | 19. Xenacoelomorpha     | 2     | 19    | 115    | 475   |         |
| Total  | 20                      | 61    | 368   | 4626   | 141,814| 1,334,834|
2.2. Division of Basic Geographical Units (BGU) and Building Databank

Based on ecological conditions and animal distributions [111], we divided the global terrestrial surface, excluding Antarctica, into 67 BGUs (Figure 1) as the basis for the clustering analyses and biodivision. Of these BGUs, 21 are plain-based, 11 are hill-based, 12 are mountains-based, 11 are plateau-based, five are desert-based, and seven are island-based. Twenty-seven BGUs are located within the tropical zone, 34 are located within the temperate zone, and six are extended to the frigid zone.

The database was created using Microsoft Access (Microsoft Corporation, New Mexico, USA), with BBUs and BGUs in rows and columns, respectively. The distribution of each animal species of a specific genus in an administrative region was converted into a BGU, summarized as the distribution of the genus, and entered into the database. If the entry was associated with a distribution, a

![Figure 1. BGUs of the World. 01 Northern Europe, 02 Western Europe, 03 Central Europe, 04 Southern Europe, 05 Eastern Europe, 06 European Russia, 11 Middle East, 12 Saudi Arabia, 13 Yemen and Oman, 14 Plateau of Iran, 15 Central Asia, 16 Western Siberia, 17 Eastern Siberia, 18 Ussuri region, 19 Mongolia, 20 Plateau of Pamir, 21 Northeastern region of China, 22 Northwestern region of China, 23 Qinghai-Xizang region of China, 24 Southwestern region of China, 25 Southern region of China, 26 Centre-eastern China, 27 Taiwan region of China, 28 Korea Peninsula, 29 Japan, 31 Himalayan region, 32 Indian and Sri Lanka, 33 Myanmar, 34 Indochina Peninsula, 35 Philippines, 36 Indonesia, 37 New Guinea, 38 Islands of Pacific Ocean, 41 Northern Africa, 42 Western Africa, 43 Central Africa, 44 Reaches of Congo river, 45 Ethiopia region, 46 Tanzania region, 47 Angola region, 48 South Africa, 49 Madagascar, 51 Western Australia, 52 Northern Territory, 53 South Australia, 54 Queensland, 55 New South Wales, 56 Victoria, 57 Tasmania, 58 New Zealand, 61 Eastern Canada, 62 Western Canada, 63 Mts. Eastern US, 64 Plain Central US, 65 Hills Central US, 66 Mts. Western US, 67 Mexico, 68 Central America region, 69 Caribbean Islands, 71 Venezuela, 72 Plateau Guyana, 73 Northern Mt. Andes, 74 Amazon Plain, 75 Plateau Brazil, 76 Bolivia, 77 Argentina, 78 Southern Mt. Andes.](image_url)
“1” was recorded in the database; otherwise nothing was recorded. These basic distributional records (BDRs) constituted the basis of the quantitative analyses. The distribution information of the major animal groups in each BGU is described in Table 2.

2.3. Clustering Methods

Although similarity formulas are more than a few dozens [112], they are only able to calculate the similarity coefficient between two regions. In this study, the similarity coefficient of multiple regions was calculated as the percentage of the average number of common species in the participating regions to the number of all species [113]. We defined the similarity general formula (SGF) as:

\[ S_{In} = \frac{\sum H_i}{nS_n} = \frac{\sum (S_i - T_i)}{nS_n}, \]

where \( S_{In} \) is the similarity coefficient of \( n \) geographical units; \( S_n \), \( H_n \), and \( T_i \) represent the number of total species, common species, and unique species of BGU \( i \); and \( H_i = S_i - T_i \); \( S_n \) is the total number of species in \( n \) BGUs. All of these values can easily be obtained from the database, which is convenient and efficient for both manual and computational analysis. We used a combination of MSCA and SGF in this study. In MSCA, the similarity coefficient of any group of BGU is calculated directly using the raw data of the participating BGUs [114], and it is not affected by the previous similarity coefficient, and furthermore, is not limited by the sequence of the clustering analysis. The general similarity coefficient (GSC) of all 67 BGUs can even be calculated first. Final dendrogram can be generated according to the size of these similarity coefficients. This method has been validated in some fauna [115]-[124], and has been successfully used for distribution pattern analysis at large geographic scales [125] [126] [127].

The results of the above method were assessed by comparison with three common hierarchical clustering methods:

The single linkage method (SLM) [128], also known as minimum distance method, is the most basic clustering analysis method. This method uses the similarity coefficient formula proposed by Jaccard (1901) [16], where,

\[ SI = \frac{C}{A + B - C}. \]

The average group linkage method (AGL), also known as the unweighted pair group means algorithm (UPGMA) [23], is a widely used clustering method. This method uses Simpson’s formula (1946) [19] proposed by Szymkiewicz [1934] (18), where \( SI = C \min (A, B) \).

The sum of squares method (SSM), also known as Ward’s method (21), usually provides better results than the above models, but involves more complex calculations. In this method, we used the similarity coefficient formula proposed by Czekanowski (1913) (17), which is also called the Sørensen formula (1948) (20), where, \( SI = 2C(A + B) \).

All three similarity coefficient formulae can only perform pairwise comparisons between regions. \( A \) and \( B \) represented the number of species in two regions, while \( C \) represented the common species shared by two regions.
Table 2. Number of genera of higher and lower of global terrestrial animal in every BGUs.

| BGU | Higher | Lower | All | BGU | Higher | Lower | All |
|-----|--------|-------|-----|-----|--------|-------|-----|
| 01  | 343    | 7845  | 8188| 44  | 848    | 3712  | 4560|
| 02  | 454    | 9983  | 10,437| 45  | 666    | 2274  | 2940|
| 03  | 507    | 8676  | 9183| 46  | 736    | 4809  | 5545|
| 04  | 589    | 11,557| 12,146| 47  | 663    | 4363  | 5026|
| 05  | 293    | 3389  | 3682| 48  | 674    | 6386  | 7060|
| 06  | 298    | 2770  | 3068| 49  | 338    | 4492  | 4830|
| 11  | 512    | 4568  | 5080| 51  | 465    | 5319  | 5784|
| 12  | 317    | 1731  | 2048| 52  | 389    | 3604  | 3993|
| 13  | 329    | 1614  | 1943| 53  | 400    | 2919  | 3319|
| 14  | 527    | 3241  | 3768| 54  | 548    | 9060  | 9608|
| 15  | 286    | 2843  | 3129| 55  | 530    | 8077  | 8607|
| 16  | 163    | 1702  | 1865| 56  | 442    | 5490  | 5932|
| 17  | 273    | 4886  | 5159| 57  | 273    | 3464  | 3737|
| 18  | 221    | 3016  | 3237| 58  | 168    | 3847  | 4015|
| 19  | 248    | 1355  | 1603| 61  | 359    | 5819  | 6178|
| 20  | 186    | 1354  | 1540| 62  | 481    | 6799  | 7280|
| 21  | 346    | 4383  | 4729| 63  | 735    | 10,015| 10,750|
| 22  | 224    | 2167  | 2391| 64  | 809    | 7433  | 8242|
| 23  | 220    | 2737  | 2957| 65  | 728    | 6280  | 7008|
| 24  | 457    | 5851  | 6308| 66  | 986    | 9327  | 10,313|
| 25  | 777    | 8159  | 8936| 67  | 1120   | 10,896| 12,016|
| 26  | 752    | 10,872| 11,624| 68  | 971    | 11,066| 12,037|
| 27  | 455    | 8382  | 8837| 69  | 510    | 4298  | 4808|
| 28  | 280    | 2050  | 2330| 71  | 1294   | 3927  | 5221|
| 29  | 343    | 7717  | 8060| 72  | 914    | 3050  | 3964|
| 31  | 644    | 2774  | 3418| 73  | 1653   | 7742  | 9395|
| 32  | 872    | 6609  | 7481| 74  | 1200   | 5418  | 6618|
| 33  | 776    | 4061  | 4837| 75  | 1259   | 6463  | 7722|
| 34  | 812    | 6201  | 7013| 76  | 932    | 2896  | 3828|
| 35  | 610    | 4248  | 4858| 77  | 1024   | 4724  | 5748|
| 36  | 1008   | 8606  | 9614| 78  | 373    | 3196  | 3569|
| 37  | 570    | 4866  | 5436| 79  | 527    | 353,581| 393,016|
| 38  | 411    | 4912  | 5323| 80  | 6890   | 134,924| 141,814|
| 41  | 463    | 4809  | 5272| 81  | 67     | 67    | 67|
| 42  | 838    | 4233  | 5071| 82  | 5.72   | 2.62  | 2.77|
| 43  | 543    | 2249  | 2792| 83  | 589    | 5277  | 5866|
3. Results

3.1. Clustering Results of Terrestrial Animal

The results of the MSCA clustering analysis of 141,814 global terrestrial faunal genera are shown in Figure 4. The GSC value was 0.066, and at a similarity of 0.300, 67 BGUs were grouped into 20 smaller unit crowds (SUCs), labeled from a to t. At a similarity of 0.200, the BGUs were further grouped into seven larger unit crowds (LUCs), labeled from A to G. Each unit within a crowd was adjacent to another unit, thereby satisfying principles of geography. The ecological conditions of each crowd were relatively consistent, which met ecological principles. In addition, intra-crowd similarity was greater than inter-crowd similarity, thereby realizing statistical principles. The MSCA clustering analysis results for the higher animals and lower animals are shown in Figure 2 and Figure 3, respectively, using the same letters for the crowds to facilitate direct comparisons. The animals grouped into seven LUCs and some SUCs at specific levels and exhibited similar crowd compositions of Figure 4. Some variation in the location of a few BGUs between two regions existed, but these nevertheless still conformed to geographical principles.

We also assessed our scheme against the existing animal biogeographical division schemes proposed by some zoologists (28, 29, 30, 34, 35, 40, 42, 43, 67). Our results are closer aligned with the biogeographical patterns proposed by Kreft using global mammal data [34], than that of Holt [40] and Procheș [30]. Our scheme supported many aspects of these proposals, including the subdivision of the Palaearctic Realm into western and eastern halves based on the distribution patterns of Trichoptera and Aleyrodidae [31] [36]; the placement of New Guinea Island and the Pacific Islands into the Oriental Realm according to the distribution of Siphonaptera and Trichoptera [42] [43]; the removal of the Pacific Islands from the Australian Realm based on the distribution patterns of freshwater insects, Aleyrodidae, and Staphylinidae [28] [31] [67]; the reintroduction of Yemen and Oman into the Palaearctic Realm based on the distribution of Symphyta and Culicidae [29] [35]; and the transferal of Mexico into the Nearctic Realm according to the distribution of Culicidae [29]. However, our analysis did not support the establishment of new realms for New Zealand, Madagascar, and Antarctica.

The establishment of B LUC is closely related to Chinese biodiversity. Modern China has the most animal genera and very much endemic genera (Table 3). Obviously, this is the great contribution of Chinese zoologists.

3.2. Comparison with Traditional Clustering Methods

The SLM results for the same dataset were chaotic and the groups were difficult to categorize (Figure 5). Most of the BGUs were considered to be noise, and when the distance between two clusters was set at 0.730, only two crowds (D and E) could be recognized. In contrast, AGL provided significantly improved results with appreciably less noise (Figure 6). When the distance value was set at 0.740,
Figure 2. Clustering tree of 6890 genera higher animals.
Figure 3. Clustering tree of 134,924 genera lower animals.
Figure 4. Clustering tree of global 141,814 genera terrestrial animal by MSCA.

Table 3. The total genera and endemic genera of every LUC, key units and Main countries.

| LUC | Total genera | Endemic genera | Key unit | Total genera | Endemic genera | Main country | Total genera | Endemic genera |
|-----|--------------|----------------|----------|--------------|----------------|--------------|--------------|----------------|
| A   | 20,855       | 5742           | 04       | 12,146       | 1004           |              |             |                |
| B   | 20,686       | 4556           | 26       | 11,624       | 819            | China        | 18,357       | 4290           |
| C   | 23,596       | 7919           | 36       | 9614         | 1372           | Indonesia    | 9614         | 1372           |
| D   | 16,588       | 8010           | 48       | 7060         | 1074           | S. Africa    | 7060         | 1074           |
| E   | 17,400       | 7997           | 54       | 9608         | 1169           | Australia    | 15,774       | 6733           |
| F   | 28,008       | 9886           | 66       | 10,313       | 985            | USA          | 17426        | 2534           |
| G   | 18,529       | 7428           | 73       | 9395         | 1057           | Brazil       | 10,669       | 1812           |
five crowds could be distinguished. Of these five crowds, four corresponded to the C, D, E, and G groups. One crowd consisting of 31 BGUs was very complex and could only be categorized into three crowds when the distance value was set at 0.550. More definitive clustering results were obtained with SSM (Figure 7). When the distance value was set at 1.40, eight crowds were obtained; among which seven were comparable to the seven crowds in the MSCA, while the remaining crowd had no geographical significance, and further categorization using SSM proved challenging. These findings indicate that these three clustering methods do not satisfy zoogeographic requirements.

3.3. A Biogeographical Division Scheme for the Global Terrestrial Fauna

Based on the clustering results, we suggest that the terrestrial world can be divided into seven kingdoms and 20 subkingdoms using an animal geographical regionalization scheme (Figure 8). This is the first geographical regionalization scheme that represents the overall global terrestrial fauna.

Our scheme showed a similar overall distribution pattern to Wallace’s scheme [9], with some notable differences. For example, in our study 1) the Palaearctic Realm is further divided into eastern and western halves; 2) New Guinea Island and the Pacific Islands are regarded as part of the Oriental kingdom as opposed
Figure 7. Clustering tree of global animal by SSM.

Figure 8. Global scheme for biogeographical divisions for terrestrial animals. A. West Palaearctic Kingdom, B. East Palaearctic Kingdom, C. Indo-Pacific Kingdom, D. Afrotropical Kingdom, E. Australian Kingdom, F. Nearctic Kingdom, G. Neotropical Kingdom. a. European Subkingdom, b. Mediterranean Subkingdom, c. Centre Asian Subkingdom, d. Siberian Subkingdom, e. Northeast Asian Subkingdom, f. Chinese Subkingdom, g. South Asian Subkingdom, h. Indonesian Subkingdom, i. Pacific Subkingdom, j. Centre African Subkingdom, k. Southern African Subkingdom, l. Madagascan Subkingdom, m. Western Australian Subkingdom, n. Eastern Australian Subkingdom, o. New Zealander Subkingdom, p. North American Subkingdom, q. Centre American Subkingdom, r. Amazonian Subkingdom, s. Argentine Subkingdom, t. Chilean Subkingdom.

4. Conclusions and Discussion

To the best of our knowledge, this constitutes the first quantitative attempt at a
division scheme for the global terrestrial fauna. The MSCA method facilitated the delineation of the global terrestrial fauna at a large geographical scale and provided more accurate clustering results than other commonly used clustering methods. Interestingly, the results obtained from the MSCA closely approached the global zoogeographic regions proposed by Wallace, but provided a quantitative validation of the scheme. MSCA can therefore be considered as a useful tool for facilitating the revision of a global biogeographical faunal division scheme.

Based on the observation that the same distribution patterns exist for higher and lower animals worldwide despite their distinct evolutionary stages, degrees of evolution, and habitats, we deduce that the same distribution patterns may also be shared among animals, plants, and microbes. Therefore, we recommend the use of quantitative analyses, such as MSCA, to establish a biogeographic division scheme for all terrestrial living organisms, including plants and microbes.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Crisp, M.D., et al. (2009) Phylogenetic Biome Conservatism on a Global Scale. Nature, 458, 754-756. https://doi.org/10.1038/nature07764
[2] Ladle, R.J. and Whittaker, R.J. (2011) Conservation Biogeography. Wiley-Blackwell, Chichester. https://doi.org/10.1002/9781444390001
[3] Lomolino, M.V., Riddle, B.R., Whittaker, R.J. and Brown, J.H. (2010) Biogeography. 4th Edition, Sinauer Associates, Sunderland, MA.
[4] Buffon, C. (1761) Histoire Nattrelle. Academic Francaise, Paris.
[5] Prichard, J.C. (1826) Researches into the Physical History of Mankind. Sherwood, Gilbert & Piper, London.
[6] Swainson, W. (1844) Geographical Considerations in Relation to the Distribution of Man and Animals. In: Murray, H., Ed., An Encyclopaedia of Geography, Longman, London, 247-268.
[7] Sclater, P.L. (1858) On the General Geographical Distribution of the Members of the Class Aves. Zoological Journal of the Linnean Society, 2, 130-136. https://doi.org/10.1111/j.1096-3642.1858.tb02549.x
[8] Wallace, A.R. (1863) On the Physical Geography of the Malay Archipelago. Royal Geographical Society, 7, 205-212.
[9] Wallace, A.R. (1876) The Geographical Distribution of Animals. Cambridge University Press, Cambridge.
[10] Darlington, P.J. (1957) Zoogeography: The Geographic Distribution of Animals. John Wiley & Sons, New York, 675 p.

[11] Cox, C.B. and Moore, P.D. (2005) Biogeography, an Ecological and Evolutionary Approach. 7th Edition, Blackwell Publishing Ltd., Hoboken.

[12] Weber, M. (1902) Der Indo-Australische Archipel und die Geschichte Seiner Tierwelt. Gustav Fischer Verlag, Jena.

[13] Mayr, E. (1944) Wallace’s Line in the Light of Recent Zoogeographic Studies. The Quarterly Review of Biology, 19, 1-14. https://doi.org/10.1086/394684

[14] Simpson, G.G. (1977) Too Many Lines: The Limits of the Oriental and Australian Zoogeographic Regions. Proceedings of the American Philosophical Society, 121, 107-120.

[15] Whittaker, R.J., Riddle, B.R., Hawkins, B.A. and Ladle, R.J. (2013) The Geographical Distribution of Life and the Problem of Regionalization: 100 Years after Alfred Russel Wallace. Journal of Biogeography, 40, 2209-2214. https://doi.org/10.1111/jbi.12235

[16] Jaccard, P. (1901) Distribution de la flore alpine dans le bassin des Dranses et dans quelques régions voisines. Bulletin de la Société Vaudoise des Sciences Naturelles, 37, 547-579.

[17] Czekanowski, J. (1913) Zarys method statystycznych w zastosowaniu do antropologii. Towarzystwo Naukowe Warszawskie, Warszawa.

[18] Szymkiewicz, D. (1934) Une contribution statistique a la geographie floristique. Acta Societatis Botanicorum Poloniae, 11, 249-265. https://doi.org/10.5586/asaap.1934.012

[19] Simpson, G.G. (1943) Mammals and the Nature of Continents. American Journal of Science, 241, 1-31. https://doi.org/10.2475/ajs.241.1.1

[20] Sørensen, T. (1948) A Method of Establishing Groups of Equal Amplitude in Plant Sociology Based on Similarity of Species Content and Its Application to Analysis of the Vegetation on Danish Commons. E. Munksgaard, København, 34 p.

[21] Ward Jr., J.H. (1963) Hierarchical Grouping to Optimize an Objective Function. Journal of the American Statistical Association, 58, 236-244. https://doi.org/10.1080/01621459.1963.10500845

[22] Kruskal, J.B. (1964) Nonmetric Multidimensional Scaling: A Numerical Method. Psychometrika, 29, 115-129. https://doi.org/10.1007/BF02289694

[23] Socal, R.R. and Michener, C.D. (1958) A Statistical Method for Evaluating Systematic Relationship. University of Kansas Science Bulletin, 38, 1409-1438.

[24] Lu, L., Li, H., He, Y., Zhang, J., Xiao, J. and Peng, C. (2018) Compositional Shifts in Ammonia-Oxidizing Microorganism Communities of Eight Geographically Different Paddy Soils—Biogeographical Distribution of Ammonia-Oxidizing Microorganisms. Agricultural Sciences, 9, 351-373. https://doi.org/10.4236/as.2018.93025

[25] Li, R. (2020) Resizable, Rescalable and Free-Style Visualization of Hierarchical Clustering and Bioinformatics Analysis. Journal of Data Analysis and Information Processing, 8, 229-240. https://doi.org/10.4236/jdaip.2020.84013

[26] Cox, C.B. (2010) Underpinning Global Biogeographical Schemes with Quantitative Data. Journal of Biogeography, 37, 2027-2028. https://doi.org/10.1111/j.1365-2699.2010.02420.x

[27] Olson, D.M., et al. (2001) Terrestrial Ecoregions of the Worlds: A New Map of Life on Earth. Bioscience, 51, 933-938. https://doi.org/10.1641/0006-3568(2001)051[0933:TEOTWA]2.0.CO;2
[28] Herman, L.H. and Ales, S. (2001) Catalog of the Staphylinidae (Insecta: Coleoptera), 1758 to the End of the Second Millennium. Vol. I-VII. Bulletin of the American Museum of Natural History, 265, 1067-1806. https://doi.org/10.1206/0003-0090.265.1.3

[29] Silver, J. (2004) World Culicidae. http://www.diptera-culicidae.ocatch.com

[30] Procheş, Ş. (2005) The World’s Biogeographical Regions: Cluster Analyses Based on Bat Distributions. Journal of Biogeography, 32, 607-614. https://doi.org/10.1111/j.1365-2699.2004.01186.x

[31] Evans, G.A. (2007) The Whiteflies (Hemiptera: Aleyrodidae) of the World and their Host Plants and Natural Enemies. USDA/Animal Plant Health Inspection Service. http://keys.lucidcentral.org/keys/v3/whitefly/PDF_PwP%20ETC/world-whitefly-catalog-Evans.pdf

[32] Roelants, K., et al. (2007) Global Patterns of Diversification in the History of Modern Amphibians. Proceedings of the National Academy of Sciences of the United States of America, 104, 887-892. https://doi.org/10.1073/pnas.0608378104

[33] de Moor, F.C. and Ivanov, V.D. (2008) Global Diversity of Caddisflies (Trichoptera: Insecta) in Freshwater. Hydrobiologia, 595, 393-407. https://doi.org/10.1007/s10750-007-9113-2

[34] Kreft, H. and Jetz, W. (2010) A Framework for Delineating Biogeographical Regions Based on Species Distributions. Journal of Biogeography, 37, 2029-2053. https://doi.org/10.1111/j.1365-2699.2010.02375.x

[35] Taeger, A., Blank, S.M. and Liston, A.D. (2010) World Catalog of Symphyta (Hymenoptera). Zootaxa, 2580, 1-1064. https://doi.org/10.11646/zootaxa.2580.1.1

[36] Morse, J.C. (2008) The Trichoptera World Checklist. Zoosymposia, 5, 372-380. https://www.researchgate.net/publication/266863088 https://doi.org/10.11646/zoosymposia.5.1.29

[37] Procheş, Ş. and Ramdhani, S. (2012) The World’s Zoogeographical Regions Confirmed by Cross-Taxon Analyses. Bioscience, 62, 260-270.

[38] Munguía, M., Rahbek, C., Rangel, T.F., Diniz-Filho, J.A.F. and Araújo, M.B. (2012) Equilibrium of Global Amphibian Species Distributions with Climate. PLoS ONE, 7, e34420. https://doi.org/10.1371/journal.pone.0034420

[39] Fritz, S.A. and Rahbek, C. (2012) Global Patterns of Amphibian Phylogenetic Diversity. Journal of Biogeography, 39, 1373-1382. https://doi.org/10.1111/j.1365-2699.2012.02757.x

[40] Holt, B.G., et al. (2013) An Update of Wallace’s Zoogeographic Regions of the World. Science, 339, 74-78. https://doi.org/10.1126/science.1228282

[41] Rueda, M., Rodriguez, M.Á. and Hawkins, B.A. (2013) Identifying Global Zoogeographical Regions: Lessons from Wallace. Journal of Biogeography, 40, 2215-2225. https://doi.org/10.1111/jbi.12214

[42] Vashchonok, V. and Medvedev, S. (2013) Fleas (Siphonaptera). http://www.zin.ru/Animalia/Siphonaptera

[43] Morrone, J.J. (2018) The Spectre of Biogeographical Regionalization. Journal of Biogeography, 45, 282-288. https://doi.org/10.1111/jbi.13135

[44] Durden, L.A. and Musser, G.G. (1994) The Sucking Lice (Insecta: Anoplura) of the World: A Taxonomic Checklist with Records of Mammalian Host and Geographical Distributions. Bulletin of the American Museum of Natural History, No. 218.

[45] Knight, K.L. and Stone, A. (1977) A Catalog of the Mosquitoes of the World (Diptera: Culicidae). Entomological Society of America, Maryland, 621 p.
[46] Price, R.D., Hellenthal, R.A., Palma, R.L., Johnson, K.P. and Clayton, D.H. (2003) The Chewing Lice. World Checklist and Biological Overview. Illinois Natural History Survey, Special Publication 24, 501 p.

[47] Takaoka, H., Sofian-Azirun, M., Ya’cob, Z., Chen, C.D., Lau, K.W., Low, V.L., Pham, X.D. and Adler, P.H. (2017) The Black Flies (Diptera: Simuliidae) of Vietnam. Zootaxa. 4261, 1-165. https://doi.org/10.11646/zootaxa.4261.1.1

[48] Wilson, D.E. and Reeder, D.M. (2005) Mammal Species of the World: A Taxonomic and Geographic Reference. John Hopkins University Press, Baltimore, MD, 2142 p.

[49] Cleere, N. (2010) Nightjars, Potoos, Frogmouths, Oilbird and Owlet-Nightjars of the World. WILDGuides Ltd., Hampshire, 464 p.

[50] del Hoyo, J., Elliot, A., Sargatal, J. and Christie, D.A. (1992-2009) Handbook of the Birds of the World. Vol. 1-14. Lynx Edicions, Barcelona, 10783 p.

[51] Ahlström, P. and Mild, K. (2003) Pipits & Wagtails of Europe, Asia and North America. Identification and Systematics. Christopher Helm, London, 496 p.

[52] Arlott, N. (2009) Birds of Europe, Russia, China and Japan. Non-Passerines: Loons to Woodpeckers. Princeton University Press, Princeton, 240 p.

[53] Ash, J. and Atkins, J. (2009) Birds of Ethiopia and Eritrea an Atlas of Distribution. Christopher Helm, London, 463 p.

[54] Borrow, N. and Demey, R. (2004) Field Guide to the Birds of Western Africa. Christopher Helm, London, 510 p.

[55] Higgins, P.J., et al. (1996-2006) Handbook of Australian, New Zealand & Antarctic birds. Volume 3-7. Snipe to Pigeons. Oxford University Press, Melbourne, 6754 p.

[56] Latta, S., Rimmer, C., Keith, A., Wiley, J., Raffaele, H., McFarland, K. and Fernandez, E. (2006) Field Guide to the Birds of the Dominican Republic & Haiti. Princeton University Press, London, 258 p.

[57] Myers, S. (2009) Birds of Borneo. Brunei, Sabah, Sarawak, and Kalimantan. Princeton University Press, Princeton, 271 p.

[58] Sinilla, I. and Ryan, P. (2003) A Comprehensive Illustrated Field Guide. Birds of Africa South of the Sahara. Struik Publishers, Cape Town, 759 p.

[59] Thévenot, M., Vernon, R. and Bergier, P. (2003) The Birds of Morocco. An Annotated Checklist. BOU Checklist No. 20. British Ornithologists’ Union & British Ornithologists’ Club, Tring, 594 p.

[60] Watling, D. (2004) A Guide to the Birds of Fiji & Western Polynesia. Environmental Consultants, Suva, 272 p.

[61] Zheng, Z.X., et al. (2008) Fauna Sinica. Passeriformes. Muscicapidae III. Sylviinae Muscicapinae. 12. Editorial Committee of Fauna Sinica, Chinese Academy of Sciences, Beijing, 439 p.

[62] Balian, E.V., Leveque, C., Segers, H. and Martens, K. (2008) The Freshwater Animal Diversity Assessment: An Overview of the Results. Hydrobiologia, 595, 627-637.
lobocondyla from China (Hymenoptera: Formicidae), with a Revised Key to the Known Species. *Zoological Systematics, 44*, 132-139.

[97] Xi, Y.Q., Shen, S., Yang, D. and Yin, X.M. (2021) Six New Species in the Genus Phylomyza Fallén (Diptera: Milichiidae) from China with a Key to Chinese Species. *Entomotaxonomia, 43*, 1-14.

[98] Liu, M.M., Li, Z.J. and Wei, M.C. (2020) Three New Species of the Macrophya Histroio group (Hymenoptera: Tenthredinidae) with a Key to Species from China. *Entomotaxonomia, 42*, 57-69.

[99] Liu, S.X., Jiyun Yang, J.Y. and Wei, M.C. (2019) Two New Species of Xiphydriidae (Hymenoptera) from Japan. *Entomotaxonomia, 41*, 165-173.

[100] Dinesh, K., Channakeshavamurthy, B., Deepak, P., Ghosh, A. and Deuti, K. (2021) Morphological Groupings within *Euphlyctis* (Anura: Dicroglossidae) and Description of a New Species from the Surroundings of Thattekad Bird Sanctuary, Kerala, India. *Zootaxa, 4990*, 329-353.

[101] Ariyama, H. (2021) Five Species of the Family Oidiidae (Crustacea: Amphipoda) Collected from Japan, with Descriptions of a New Genus and Four New Species. *Zootaxa, 5067*, 485-561.

[102] Ralph, T.M.C., Richards, L.R., Taylor, P.J., Napier, M.C. and Lamb, J.M. (2015) Revision of Afro-Malagasy *Otomops* (Chiroptera: Molossidae) with the Description of a New Afro-Arabian Species. *Zootaxa, 4057*, 1-49. https://doi.org/10.11646/zootaxa.4057.1.1

[103] Feijo, A., Rocha, P.A.D. and Althoff, S.L. (2015) New Species of *Histiotus* (Chiroptera: Vespertilionidae) from Northeastern Brazil. *Zootaxa, 4048*, 412-427. https://doi.org/10.11646/zootaxa.4048.3.4

[104] Carleton, M.D., Banasiak, R.A. and Stanley, W.T. (2015) A New Species of the Rodent Genus *Hylomyscus* from Angola, with a Distributional Summary of the *H. anselli* Species Group (Muridae: Murinae: Praomyini). *Zootaxa, 4040*, 101-128. https://doi.org/10.11646/zootaxa.4040.2.1

[105] Csorba, G., Gorfol, T., Wiantoro, S., Kingston, T., Bates, P.J.J. and Huang, J.C. (2015) Thumb-Pads up—A New Species of Thick-Thumbed Bat from Sumatra (Chiroptera: Vespertilionidae: Glischropus). *Zootaxa, 3980*, 267-278. https://doi.org/10.11646/zootaxa.3980.2.7

[106] Goodman, S.M., Ramasindrazana, B., Naughton, K.M. and Appleton, B. (2015) Description of a New Species of the *Miniopterus aelleni* Group (Chiroptera: Miniopteridae) from Upland Areas of Central and Northern Madagascar. *Zootaxa, 3936*, 538-558. https://doi.org/10.11646/zootaxa.3936.4.4

[107] Soisook, P., Prajakjitr, A., Karapan, S., Francia, C.M. and Bates, P.J.J. (2015) A New Genus and Species of False Vampire (Chiroptera: Megadermatidae) from Peninsular Thailand. *Zootaxa, 3931*, 528-550. https://doi.org/10.11646/zootaxa.3931.4.4

[108] Huerta, H. and Grogan Jr., W.L. (2017) New Species and New Records of Predaceous Midge in the Genera, *Schizonyxhelea* Clastrier and *Stilobezzia* Kieffer from Mexico (Diptera: Ceratopogonidae). *Zootaxa, 4294*, 401-418. https://doi.org/10.11646/zootaxa.4294.4.1

[109] Ronderos, M.M., Spinelli, G.R. and Grogan Jr., W.L. (2017) The Neotropical Species of the Predaceous Midge Genus *Austrobelea* Wirth & Grogan (Diptera: Ceratopogonidae). *Zootaxa, 4276*, 255-269. https://doi.org/10.11646/zootaxa.4276.2.7

[110] Natarajan, R., Rajavel, A.R. and Jambulingam, P. (2017) Descriptions of Three New species of *Uranotaenia* (Pseudotalibia) Diptera: Culicidae) from India. *Zootaxa,
Q. Shen et al.

4227, 251-265. https://doi.org/10.11646/zootaxa.4227.2.6

[111] Shen, Q., Ma, X.J., Ren, Y.D. and Shen, X.C. (2018) The Distribution Patterns of Main Ecological Groups of Insects in the World and Its Ecological Significance. *International Journal of Ecology, 7*, 170-184. https://doi.org/10.12677/IJE.2018.73019

[112] Zhang, J.L. (1998) An Important Index: The Coefficient of Similarity of Flora. *Geographical Research, 17*, 429-434.

[113] Shen, X.C. and Wang, A.P. (2008) A Simple Formula for Multivariate Similarity Coefficient and Its Contribution Rate in Analysis of Insect Fauna. *Journal of Henan Agricultural Sciences*, No. 7, 67-69.

[114] Shen, X.C., Sun, H. and Zhao, H.D. (2008) A Discussion about the Method for Multivariate Similarity Analysis of Fauna. *Acta Ecologica Sinica, 28*, 849-854.

[115] Shen, X.C., Sun, H. and Ma, X.J. (2010) The Multivariate Similarity Clustering Analysis for 40000 Species of Insect and Spider in China. *Journal of Life Sciences, 4*, 35-40.

[116] Shen, X.C., Ren, Y.D., Wang, A.P. and Zhang, S.J. (2010) A Multivariate Similarity Clustering Analysis for Geographical Distribution of Insects, Spiders and Mites in Henan Province. *Acta Ecologica Sinica, 30*, 4416-4426.

[117] Shen, X.C., Liu, X.T., Ren, Y.D., Shen, Q., Liu, X.T. and Zhang, S.J. (2013) The Multivariate Similarity Clustering Analysis and Geographical Division of Insect Fauna in China. *Acta Entomologica Sinica, 56*, 896-906.

[118] Shen, X.C., et al. (2015) Insect Geography of China. Henan Science and Technology Press, Zhengzhou, 980 p.

[119] Shen, Q. (2014) Multivariate Similarity Clustering Analysis for Distribution of the Medical Insect in China. *Acta Parasitological et Medica Entomologica Sinica, 21*, 165-171.

[120] Shen, Q., You, Z.X., Ma, X.J. and Shen, X.C. (2020) Biogeography of Medically Important Insects Using Quantitative Analysis. *Global Journal of Medical Research, 20*, 1-11.

[121] Shen, X.C., Ren, Y.D., Ma, X.J., Feng, C.H., Zhang, S.J., Wang, G.H. and Yang, L.L. (2018) Clustering Analysis and Biogeographical Regionalization of Distribution Patterns of Dicotyledonoud Plants in the World. *Botanical Research, 7*, 405-417. https://doi.org/10.12677/BR.2018.74049

[122] Shen, X.C., Ren, Y.D., Shen, Q., Zhang, S.J., Ma, X.J., Yang, L.L., Wang, G.H. and Feng, C.H. (2018) The Homogeneity of Distribution Pattern of Chinese Terrestrial Biota. *Open Journal of Nature Science, 6*, 373-382. https://doi.org/10.12677/OJNS.2018.64048

[123] Shen, X.C., Ren, Y.D., Shen, Q., You, Z.X., Liu, X.T., Zhang, S.J., Wang, G.H., Yang, L.L., Feng, C.H. and Ma, X.J. (2018) The Macroscopic Characteristics of Distribution of Global Terrestrial Biota. *International Journal of Ecology, 7*, 98-128. https://doi.org/10.12677/IJE.2018.72014

[124] Shen, Q., Ma, X.J., You, Z.X. and Shen, X.C. (2021) The Distributional Patterns of Medical Insects in the World and Its Relation with Other Biota. *International Journal of Ecology, 10*, 558-575. https://doi.org/10.12677/IJE.2021.104064

[125] Shen, X.C., Zhang, B.S., Zhang, F. and Liu, X.T. (2013) Worldwide Distribution and Multivariate Similarity Clustering Analysis of Spiders. *Acta Ecologica Sinica, 33*, 6795-6802. https://doi.org/10.5846/stxb201207080951

[126] Shen, X.C., Zhang, S.J., Shen, Q., Hu, G.L. and Lu, J.Q. (2021) Multivariate Similarity Clustering Analysis: A New Method Regarding Biogeography and Its Applica-
tion in Global Insects. *Integrative Zoology*, **16**, 390-403. https://doi.org/10.1111/1749-4877.12485

[127] Shen, X.C., et al. (2021) Insect Geography of the World. Henan Science and Technology Press, Zhengzhou, 541 p.

[128] Gower, J.C. and Ross, G.J.S. (1969) Minimum Spanning Trees and Single Linkage Cluster Analysis. *Journal of the Royal Statistical Society. Series C*, **18**, 54-64. https://doi.org/10.2307/2346439