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The Macroscopic Characteristics of Distribution of Global Terrestrial Biota

—Biogeographical Regionalization Research III

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Abstract

In order to analyze the distributional law of terrestrial organisms, we analyzed the global distribution pattern of animals, plants and microorganisms using multivariate similarity clustering analysis method, and gradually clarified and confirmed several macroscopic features of the biota distribution. The distribution of biological species is likely to be disconnected, but the change of the floristic or faunal composition between regions is continuous; the farther the distance, the greater the difference. The similarity of a geographical area is only highest with adjacent areas, and its clustering object can only be adjacent areas. This restrictive condition brings convenience for geographic regionalization; biological distribution is not balanced. The richer biodiversity areas can play a key role in the clustering analysis. Their cohesion and independence are the inner motive power of biological regional formation. Although a geographic area's species diversity increases with the deepening of the research, its floristic or faunal composition is relatively stable, to ensure the stability of distributional pattern and measurability of biogeographical regionalization. Though different evolution periods between animals, plants and fungus, life form and manner of metabolism were different, their global distribution patterns were the same. This homogeneity will promote the reveal of biological distributional law and the development of biological geography.

Keywords

Biogeography, Regionalization, Cluster Analysis, Distributional Characteristics

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世界生物分布的宏观特征

—生物地理区划研究之 III

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摘 要

为了解析陆生生物的分布规律，应用我们新提出的多元相似性聚类分析方法，对全球的动物、植物、菌物的分布格局进行分析，逐渐明晰并证实世界生物分布的几项宏观特征：生物物种的分布可能是间断的，但地区间区系组成的变化是连续的，距离愈远，变化愈大；一个地理区域只与相邻地区相似性最高，它的聚类对象只能是相邻地区，这种地域约束性为地理区划带来便利；生物分布的不均衡性使多样性丰富地区在聚类分析中发挥核心作用，它的凝聚力及独立性是生物分布区形成的内在动力；一个地理区域的物种多样性随着调查的深入不断增加，但它的区系构成是相对稳定的，这种稳定性保证了这个地区生物区系性质和地理区划的稳定性与可测性，是生物地理学科产生的基础；动物、植物和菌物虽然进化时期不同，生命形态及新陈代谢方式也不同，但它们在全球的分布格局是相同的，由生态因素对生物分布的这种同质性影响将会促进对生物分布规律的揭示和生物地理学科的发展。

关键词

生物地理学，地理区划，聚类分析，分布特征

1. 引言

世界 1.49 亿平方千米陆地上，生活着 200 多万种生物。它们以不同的生命形态遍布世界各个角落。陆块的漂移、山地的隆起、气候的变化、海洋的阻隔等影响着生物的繁衍与扩散，生物也以自身的进化与适应能力构建自己的分布格局。没有任何两种生物的分布区域完全相同，也没有任何两个地理区域的生物种类完全相同。对生物分布规律及形成机制的分析与总结，并进而进行地理分布区的划分是生物地理学的研究范畴。它既是人们保护生物多样性的重要基础学科，又是达到合理有效、永续利用自然资源的有效工具[1] [2] [3]。

生物地理学由法国博物学家布丰 1761 年创立以来[4]。19 世纪，英国鸟类学家斯克莱特(P. Sclater)根据鸟类特别是雀形目 Passeriformes 的分布，英国动物学家华莱士(A. R. Wallace)主要根据哺乳动物的分布，共同奠定了动物地理学的基础，提出 6 界 24 亚界的动物地理区划方案[5] [6]。德国植物学家洪堡(A. von Humboldt)于 1805 年奠基植物地理学后[7]，瑞士学者德康得勒(A. de Candolle)和德国学者恩格勒(A. Engler)根据有花植物的分布构建了植物地理学大厦[8] [9]。后经人们修改[10] [11] [12] [13]，也形成了与动物不同的 6 界区划系统。他们这些 19 世纪的阐释为人们普遍接受并持续使用着[14]。

人们的普遍接受并长期使用，自然说明它的合理内核。但也无须讳言，由定性方法得到的这些结论不可避免地在划分标准及分界线的确定上存在失衡之处。整个 20 世纪探索生物地理的脚步并未停止。人们一方面讨论早期学者们的历史功绩及存在问题[15] [16] [17] [18] [19]，另一方面积极尝试用定量分析的方法装备生物地理学[20]-[29]。人们逐渐形成共识，数学的介入与支撑应是生物地理学发展的不可回避或逾越的重要途径。否则它是不可能真正成熟的[30]。

进入 21 世纪，人们对生物地理区划的关注迅速高涨起来[31]-[36]。用不同的方法对不同的生物类群分别提出 7-14 界的形形色色的、各不相同的地理区划方案[37]-[47]。C.B. Cox 提出建议，撤掉植物地理新设的好望角界及南极界，同时将古热带界分成非洲界及印度－太平洋界[41]。吴征镒提出增设古地中海植物界和东亚植物界[42]。S. Proches 对蝙蝠的分布进行聚类分析，将世界分作 10 个地理区，并认为适用于动物地理和植物地理[43]。H. Kreft 用 Simpson 公式及 UPGMA 法将世界聚为 7 个界，除新设马达加斯加界以外，其它界的分界线也有所变动[44]。B.G. Holt 等同样用 Simpson 公式及 UPGMA 聚类方法对陆生哺乳动物、两栖动物、非海洋鸟类共 20,000 多个物种进行分析，把全世界分成 11 个界[45]。而 M. Rueda 同样对这些动物进行分析，认为不必修改华莱士方案[46]。E.J. Defriez 和 D.C. Reuman 共同论证了世界陆地植被变化的同步性(synchrony) [47]。

与热烈讨论的高等生物地理区划相比，低等生物非常冷清。虽然昆虫学家已有数百篇涉及昆虫地理学文献[48] [49] [50]。但直至近 20 年，才陆续对昆虫的个别类群，如毛翅目、蚤目、广腰亚目、隐翅虫科、粉虱科、金龟科、蚁科昆虫进行分析，提出各自的地理区划意见[51]-[58]。而微生物至今还没有人进行初步的尝试[59]-[68]。

综观生物地理学两个半世纪的发展历程，① 还基本处于定性分析阶段。尚未与数学有效融合。原因是缺少令生物地理学者满意的数学工具，不能够真正进入定量分析阶段；② 分析对象只注重高等生物，很少顾及低等生物；③ 对分布规律的探讨还处在对个别类群、个别地域的描述、统计阶段，缺少高阶元、广区域的比较、分析，更没有宏观规律的揭示；④ 对分布格局形成机制的认知还比较模糊、零碎，缺乏系统化、整体性的整理。因此，目前生物地理区划研究呈现分散、孤立、机遇的状态，不能够进行有组织的、系统化的协作攻关。以致成为困扰生物地理学发展的幽灵[69]。

我们在对多种定量分析方法进行尝试与比较后，提出一个新的相似性通用公式(Similarity general formula, SGF) [70]和与之配套的多元相似性聚类分析法(Multivariate similarity clustering analysis method, MSCA) [71]。经过对不同地理区域、不同生物类别、不同分类阶元、不同生态类群的分析验证，均比传统方法能够得到快捷、准确、合理的分析结果[72]-[79]。鉴于 MSCA 法的简便快捷，我们在对全球昆虫进行分析的基础上[80]，组织团队力量对世界范围内的陆生生物的分布格局进行分析。本文先行报告在大型分析中所逐渐感悟到的生物分布的几个宏观特征。

2. 材料和方法

2.1. 生物类群

世界生物共 7 界 96 门 352 纲 1466 目，约 280 万种[81]。排除海洋种类、化石种类、藻类、病毒及原

生生物，本研究涉及的生物类群包括动物、植物、真菌、细菌共 4 界 33 门 99 纲 530 目 4922 科 169,153 属 2,139,974 种(表 1)。种类分布信息来源于生物分类学家整理的分类学专著或名录[82]-[187]，生物专业性网站整理的数据库资料[188]-[250]，也随时补充一些新发表的新种、新分布资料[251]-[301]。本着提高分布资料的利用率及分析结果的清晰度，本研究以属级阶元作为分析的基础生物单元(basic biological units, BBU)。

2.2. 基础地理单元的划分

按照地形、气候等生态条件和生物分布资料的详略程度，本研究把全球陆地(除南极洲)划分为 67 个基础地理单元(basic geographical unit, BGU) (图 1)。作为聚类分析与地理区划的基础。其中以平原为主的 BGU 有 21 个，以丘陵为主的 BGU 有 11 个，以山地为主的 BGU 有 12 个，以高原为主的 BGU 有 11 个，以荒漠为主的 BGU 有 5 个，岛屿型的 BGU 有 7 个。有 27 个 BGU 处在热带，有 34 个 BGU 地处温带，有 6 个 BGU 的地域跨入寒带。

01 北欧 Northern Europe，02 西欧 Western Europe，03 中欧 Central Europe，04 南欧 Southern Europe，05 东欧 Eastern Europe，06 俄罗斯欧洲地区 European Russia，11 中东 Middle East，12 沙特阿拉伯 Saudi Arabia，13 也门与阿曼 Yemen and Oman，14 伊朗高原 Plateau of Iran，15 中亚 Central Asia，16 西西伯利亚 Western Siberia，17 东西伯利亚 Eastern Siberia，18 乌苏里地区 Ussuri region，19 蒙古 Mongolia，20 帕米尔高原 Plateau of Pamir，21 中国东北 Northeastern region of China，22 中国西北 Northwestern region of China，23 中国青藏地区 Qinghai-Xizang region of China，24 中国西南地区 Southwestern region of China，25 华南地区 Southern region of China，26 中国中东部 Centre-eastern China，27 中国台湾 Taiwan region of China，28 朝鲜半岛 Korea Peninsula，29 日本 Japan，31 喜马拉雅地区 Himalayan region，32 印度与斯里兰卡 Indian and Sri Lanka，33 缅甸 Myanmar，34 中南半岛 Indochina Peninsula，35 菲律宾 Philippines，36 印度尼西亚 Indonesia，37 新几内亚 New Guinea，38 太平洋岛屿 Islands of Pacific Ocean，41 北非 Northern Africa，42 西非 Western Africa，43 中非 Central Africa，44 刚果河流域 Reaches of Congo river，45 埃塞阿比亚地区 Ethiopia region，46 坦桑尼亚地区 Tanzania region，47 安哥拉地区 Angola region，48 南非 South Africa，49 马达加斯加 Madagascar，51 西澳大利亚 Western Australia，52 澳大利亚北部地区 Northern Territory，53 南澳大利亚 South Australia，54 昆士兰 Queensland，55 新南威尔士 New South Wales，56 维多利亚 Victoria，57 塔斯马尼亚 Tasmania，58 新西兰 New Zealand，61 加拿大东部 Eastern Canada，62 加拿大西部 Western Canada，63 美国东部山地 Mts. Eastern US，64 美国中部平原 Plain Central US，65 美国中部丘陵 Hills Central US，66 美国西部山地 Mts. Weatern US，67 墨西哥 Mexico，68 中美地区 Central America region，69 加勒比海岛屿 Caribbean Islands，71 委内瑞拉 Venezuela，72 圭亚那高原 Plateau Guyana，73 安第斯山脉北段 Northern Mt. Andes，74 亚马孙平原 Amazon Plain，75 巴西高原 Plateau Brazil，76 玻利维亚 Bolivia，77 阿根廷 Argentina，78 安第斯山脉南段 Southern Mt. Andes。

Figure 1. BGUs of the world
图 1. 世界基础地理单元的划分

Table 1. Biodiversity of global terrestrial biota
表 1. 全球陆生生物多样性

界 Kingdom	门数 No. of Phylum	纲数 No. of Classes	目数 No. of Orders	科数 No. of Families	属数 No. of Genera	种数 No. of Species
动物 Animalia	9	34	232	3474	133,505	1,253,211
植物 Plantae	13	20	122	724	27,092	655,774
真菌 Fungi	7	37	140	575	7574	223,920
细菌 Bacteria	4	8	36	149	982	7069
合计 Total	**33**	**99**	**530**	**4922**	**169,153**	**2,139,974**

注：各生物类群数据为综合汇总本文所有参考资料种类信息而成。

2.3. 构建生物分布数据库

用微软 Access 构建数据库，将各个 BGU 作为各列，将各个 BBU 作为各行。将一个属内每种生物分布的行政区域记录转化为 BGU 记录并汇总为该属分布，录入数据库中，有分布记“1”，无分布不记。本文涉及的几类生物在各 BGU 的属数如表 2。

2.4. 聚类分析方法

前人提出的数十个相似性系数计算公式[302]，但都是只能计算两个地区间的相似性系数，我们提出的相似性通用公式突破了二元比较的束缚。它的定义是：多个地区间的相似性系数是参加分析的各个地区的共有种类的平均数占总种类的比例[69]。相伴提出的还有相异性公式、相似性贡献率公式、相异性贡献率公式：

相似性通用公式(similarity genera formula, SGF)：

$$SI_n = \sum H_i / nS_n = \sum (S_i - T_i) / nS_n \tag{1}$$

相异性通用公式(difference general formula, DGF)：

$$DI_n = 1 - SI_n = \left[nT + \sum (H - H_i) \right] / nS \tag{2}$$

相似性贡献率公式(contribution of the similarity, CSI)：

$$CSI_i = H_i / \sum H_i \tag{3}$$

相异性贡献率公式(contribution of the difference, DSI)：

$$CDI_i = (nT_i + H - H_i) / \left(nS - \sum H_i\right) \tag{4}$$

式中，SI_n 是 n 个地理单元的相似性系数，S_i，H_i 和 T_i 分别是 i 地理单元的种类数、共有种类(common species)数、独有种类(unique species)数，且满足 $H_i = S_i - T_i$，S_n 是 n 个地理单元的总种类数。计算时所需各个数值都可以很方便地从数据库的查询页面上获得。无论手工计算或计算机软件分析都非常方便快捷。

与 SGF 配套使用的多元相似性聚类分析法(MSCA)是任何组群的相似性系数都由参与分析的 BGU 原始数据直接计算，不受聚类顺序的限制。甚至可以先行计算 67 个 BGU 的总相似性系数。最后按相似性系数大小排列聚类图[70]。总相似性系数、总相异性系数、各个 BGU 的相似性贡献率、相异性贡献率都是传统分析方法所没有的概念和无法计算的指标。

Table 2. The distribution of several groups biota in BGUs
表 2. 几类生物在各 BGU 分布的属数

地理单元 BGU	动物 Animalia	脊索动物 Chordata	节肢动物 Arthropoda	双子叶植物 Magnoliophyta	子囊菌 Ascomycota
01	6603	343	5931	1407	1386
02	8147	454	7089	1394	1027
03	8063	507	7071	1403	1066
04	10155	589	8842	1682	1054
05	3360	293	2931	491	299
06	2591	298	2261	420	372
11	4255	512	3579	1123	329
12	1363	317	1023	565	93
13	1433	329	1065	752	136
14	3401	527	2797	1110	138
15	2941	286	2640	402	71
16	1725	163	1554	275	120
17	4564	273	4217	308	161
18	3016	221	2778	509	256
19	1567	248	1314	248	92
20	1482	186	1286	379	37
21	4664	346	4303	305	106
22	2322	224	2091	310	61
23	2859	220	2625	432	59
24	6278	457	5803	877	71
25	8391	777	7503	1823	294
26	11195	752	10309	1488	153
27	8381	455	7841	1327	149
28	2100	280	1792	451	212
29	6396	343	5875	700	298
31	3380	644	2704	1050	154
32	6401	872	5303	1257	199
33	4417	776	3512	1142	169
34	6599	812	5643	1477	88
35	3874	610	3137	1092	154
36	7990	1008	6744	1725	319
37	4472	570	3719	1479	349
38	3630	411	2987	1442	294
41	4074	463	3372	1000	312
42	4342	838	3365	1932	106
43	2669	543	2115	1436	65
44	4245	848	3241	1462	92

Continued

45	2519	666	1765	1161	84
46	4979	736	4114	1588	162
47	4477	663	3709	1603	159
48	5735	674	4886	1770	294
49	3966	338	3503	1480	156
51	4229	465	3567	1157	398
52	2995	389	2454	1048	233
53	2540	400	1931	906	182
54	7768	548	6525	1623	455
55	3771	530	5726	1522	354
56	4690	442	3962	820	378
57	2826	273	2386	577	397
58	2319	168	2004	864	913
61	4909	359	4281	570	607
62	5914	481	5149	1268	567
63	8169	735	6780	1675	620
64	6745	806	5432	1268	398
65	6041	728	4824	1185	301
66	8605	986	7122	2084	619
67	10250	1120	8417	2851	631
68	10528	971	9248	2060	620
69	3468	510	2767	1286	282
71	4418	1294	3004	1649	240
72	3650	914	2720	1366	307
73	8407	1653	6593	2797	404
74	5984	1200	4711	1847	529
75	6542	1259	5171	1795	750
76	3774	932	2783	1669	84
77	4940	1024	3774	1378	295
78	2535	373	2081	881	444
BGR	334,038	39,435	281,751	80,423	22,104
BBU	133,505	6890	120,379	20,809	5286

注：BGU 基础地理单元：basic geographical unit；BGR 基础分布记录：basic distributional record；BBU 基础生物单元：basic biological unit。各 BGU 的属数为综合汇总所有参考文献的分布信息而成。

3. 结果与分析

3.1. 区系变化的连续性

生物种或属的分布有连续的，更有间断的。但不同地区间生物区系组成的变化是连续的，不是间断的。地理距离愈远，变化愈大。而不同方向上变化的速率是不同的。也即一个地区的生物区系，只与邻近地区关系密切，距离愈远，关系愈疏远。这种不均衡的连续性变化是开展生物地理研究，划分地理分

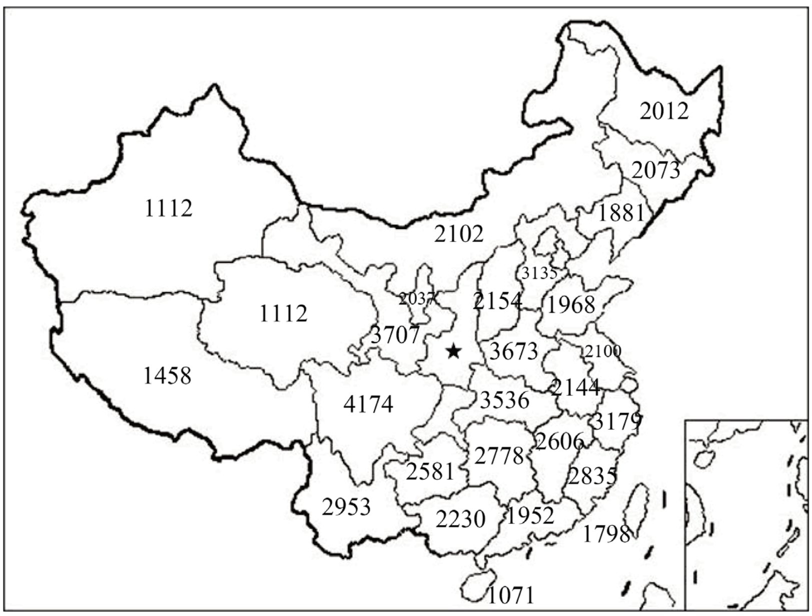
布区的基础。中国如此，世界也如此。以中国各省区昆虫为例，陕西省昆虫有 7934 种，各省区与陕西的共有种类如图 2。

3.2. 地理条件的约束性

由于一个地理区域的生物区系，只与相邻地区关系最密切，地理距离愈远，关系愈疏远。所以一个特定地区只与邻近地区产生聚类关系(图 3)，而不能够与甚远的地区相聚，形成互不相连的“飞地”。这个特征使生物地理的聚类分析成为一种带约束的聚类(restrictive clustering)或称条件系统聚类(conditional hierarchical clustering)，不是人们想象或期望中的“自由聚类”。这种约束性为软件分析带来很大的挑战，但也为手工计算带来便利，不必广泛地寻找、测试聚类伙伴，可以节省 80%以上的无效劳动时间。其它实用聚类分析项目也会遇到约束性问题。这些形形色色的限制条件是聚类分析由理论走向实用的将常遇到又必须解决的关键问题之一。

3.3. 核心区域的凝聚力与独立性

受历史条件、自然条件、适应能力、以及人为因素的影响，生物分布不是均匀的。存在着若干个多样性丰富的核心区域。核心区域以其大量的共有类群(common group)凝聚邻近区域形成自己的分布区，又以自己的特有类群(endemic group)或独有类群(unique group)标志与其它分布区的独立性。聚集力量相等的地方是分布区的分界线。这种生物分布的集中性是分布区形成的内在原因。生物地理区划实际上是用聚类分析的定量方法对这些核心区域的凝聚力与独立性进行评估，准确地界定各个分布区域的地理范围。如世界共有昆虫 104,344 属，有具体分布记录的 58,357 属在 0.300 的相似性水平上聚为 a~t 共 20 个小单元群(small unit crowd, SUC)，在 0.200 时聚为 A~G 共 7 个大单元群(large unit crowd, LUC)。表 3 是各个 BGU 的相似性贡献率和相异性贡献率，显然 04、26、36、48、54、68、73 号 BGU 是各大单元群的核心区域，对分布区的形成具有关键作用。



注：两个地区间的共有种类数表明关系的亲密程度。新疆、青海、西藏、海南没有四川、甘肃、河南、湖北与陕西关系密切。

Figure 2. The common insect species of every province with Shaanxi
图 2. 中国各省区与陕西省(★)共有昆虫种类数

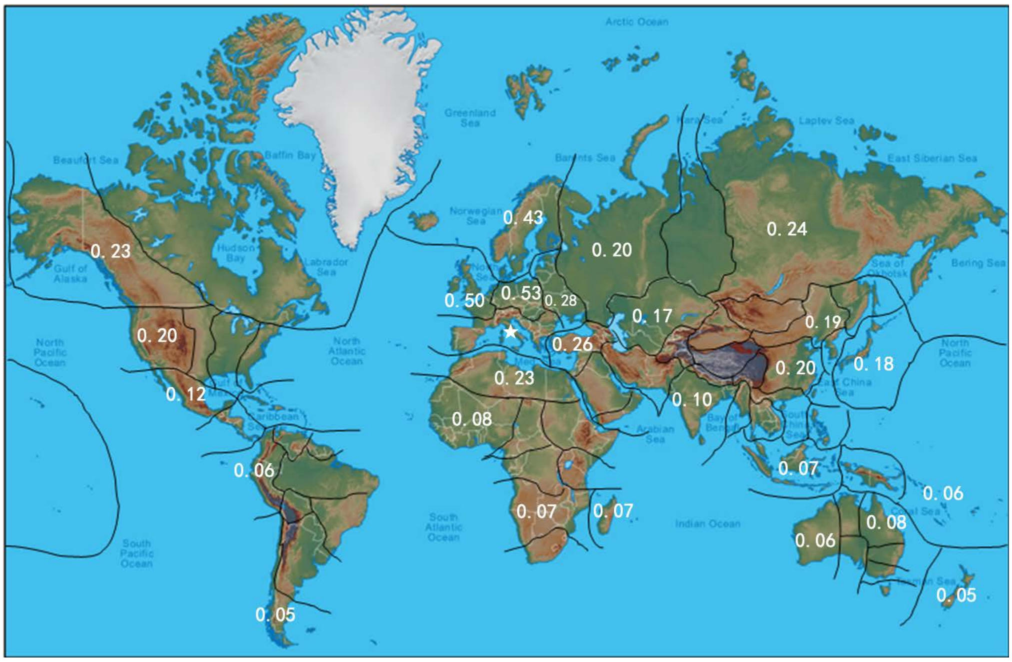


Figure 3. The similarity coefficient of animal genera of some BGUs with southern Europe
图 3. 一些 BGUs 与南欧地理单元(★)的动物属级相似性系数

Table 3. The contribution of similarity and difference of every BGU
表 3. 各个 BGU 的昆虫属级相似性贡献率与相异性贡献率

大单元群 LUC	小单元群 SUC	地理单元 BGU	属数 Genera	特有属 Unique genera	共有属 Common genra	相似性贡献率(%) CSI	相异项 $nT_i + H - H_i$	相异性贡献率(%) CDI
A	a	01	5116	115	5001	2.20	38,684	1.05
		02	6047	174	5873	2.59	41,765	1.13
		03	5882	124	5758	2.54	38,530	1.05
		04	7515	640	6875	3.03	71,985	1.95
		05	2469	21	2448	1.08	34,939	0.95
		06	2030	20	1990	0.88	35,330	0.96
	b	11	3002	151	2851	1.26	43,246	1.17
		41	2920	235	2685	1.18	49,040	1.33
		12	956	18	938	0.41	36,248	0.98
		13	956	37	919	0.40	37,540	1.02
	c	14	2508	133	2375	1.05	42,516	1.15
		15	2391	107	2284	1.01	40,865	1.11
		20	1142	40	1102	0.49	37,558	1.02
		22	1827	58	1769	0.78	38,097	1.03
B	d	16	1378	8	1370	0.60	35,146	0.95
		17	3920	36	3884	1.71	34,508	0.94
		19	1164	13	1151	0.51	35,700	0.97
		21	3923	102	3821	1.68	38,993	1.06

Continued

	e	18	2535	151	2384	1.05	43,713	1.19
		28	1404	14	1390	0.61	35,528	0.96
		29	5213	401	4812	2.12	58,035	1.58
	f	23	2223	71	2152	0.95	38,585	1.05
		24	5340	186	5154	2.27	43,288	1.18
		26	9567	747	8820	3.89	77,209	2.10
		27	7477	827	6650	2.93	84,739	2.30
		31	2379	158	2221	0.98	44,345	1.20
C	g	25	7058	367	6691	2.95	53,878	1.46
		32	4911	667	4244	1.87	76,425	2.08
		33	3179	79	3100	1.37	38,173	1.04
		34	5256	264	4992	2.20	48,676	1.32
	h	35	2817	282	2535	1.12	52,339	1.42
		36	6168	1074	5094	2.24	102,844	2.79
		37	3379	595	2784	1.23	72,061	1.96
	i	38	2560	610	1950	0.86	74,900	2.03
D	j	42	3090	287	2803	1.23	52,406	1.42
		43	1915	137	1778	0.78	43,381	1.18
		44	2976	357	2619	1.15	57,280	1.56
		45	1559	105	1454	0.64	41,561	1.13
	k	46	3796	624	3192	1.40	74,596	2.03
		47	3324	329	2995	1.32	55,028	1.49
		48	4210	821	3389	1.49	87,598	2.38
	l	49	3159	1200	1959	0.86	114,421	3.11
E	m	51	2825	375	2450	1.08	58,655	1.59
		52	2009	93	1916	0.84	40,295	1.09
		53	1599	71	1528	0.67	39,209	1.06
	n	54	5689	854	4835	2.13	88,363	2.40
		55	5004	542	4462	1.97	67,832	1.84
		56	3417	279	3138	1.38	51,535	1.40
		57	1919	178	1741	0.77	46,165	1.25
	o	58	1610	627	983	0.43	77,006	2.09
F	p	61	3677	53	3624	1.60	35,907	0.97
		62	4328	133	4195	1.85	40,696	1.10
		63	5830	268	5562	2.45	53,936	1.46
		64	4529	78	4451	1.96	36,755	1.00
		65	4229	107	4122	1.82	39,027	1.06
		66	6238	646	5592	2.46	73,670	2.00
	q	67	7518	710	6805	3.00	76,745	2.08
		68	8656	1676	6980	3.07	141,292	3.84
		69	2360	255	2105	0.93	50,960	1.38

Continued

G	r	71	2666	120	2546	1.12	41,474	1.13
		72	2544	158	2386	1.05	44,180	1.20
		73	6015	792	5223	2.30	83,821	2.28
		74	4220	455	3765	1.66	62,700	1.70
	s	75	4502	686	3816	1.68	78,126	2.12
		76	2514	81	2433	1.07	38,974	1.06
		77	3176	268	2908	1.28	51,028	1.39
	t	78	1669	487	1182	0.52	67,427	1.83
合计			249,384	22,377	227,007	100.00	3,682,912	100.00
全世界			58,357	22,377	35,980			

Note: LUC: large unit crowd; SUC: small unit crowd; BGU: basic geographical unit; CSI: contribution of the similarity; CDI: contribution of the difference.

3.4. 区系构成的稳定性

一个相对独立的地理区域的生物区系是各种环境因素长期作用的结果，其种类是随着调查研究的深入在不断增加的，但区系构成又是相对稳定的。这种稳定性保证了这个地区生物区系性质和地理区划的稳定性与可测性，是生物地理学科产生的基础。不同时期的构成是稳定的，不同生物类群的构成也是稳定的。如中国河南省目前有昆虫 8422 种，其中中国种类最多，其次是古北种类，再次是东洋种类，广布种类最少。而该省在 1993 年以前有昆虫 3128 种，也是中国种类最多，依次是古北种类、东洋种类及广布种类。中国目前的 93,661 种昆虫与上世纪 40 年代的 20,069 种也是如此。目前世界哺乳动物 5412 种与 1876 年前华莱士时代已知哺乳动物 2034 种的分布格局也是相同的，分别在 0.120 和 0.200 时聚成 7 个单元群，各群的组成也相同。只有 15、69 号 BGU 在相邻群间移动，不违背地理学原则(表 4，图 4，图 5)。

3.5. 环境对生物分布影响的同质性、积累性

在生物漫长的进化过程中，地球板块分分合合，气候不断地冷热干湿变化，生物类群的诞生与灭绝，逐渐形成现在的分布格局。虽然它们的出现时间不同，经历的历史变迁不同，但现生生物的属级阶元大都出现在新生代，它们都经受了迄今 6700 万年的新生代的环境影响，决定了它们的总体分布格局应该是相同的，也就表明环境对各类生物影响的同质性。这种同质性是我们创建世界生物地理区划体系的理论基础，可以使研究不同生物类群的学者不再单打独斗，可以联合起来共同谱写生物地理的新篇章。图 6~9 是脊索动物门、节肢动物门、双子叶植物门、子囊菌门四类主要生物的聚类结果。而更高或更低的分类阶元的分析结果也表现出同样明显的同质性特征(表 5)。

但由于各类生物出现的历史时期不同，早分化的类群比晚分化的类群要多留下些生存信息于后代，主要体现在总相似性系数(general similarity coefficient, GSC)和平均分布域(average distributional territory, ADT)的差异，微生物出现最早，分布最广，GSC 最高，为 0.125，ADT 最广，为 4.80；植物次之，GSC 为 0.112，ADT 为 4.63；动物最晚，GSC 为 0.061，ADT 为 2.50。这是历史环境影响的积累性(表 5)。

4. 结论与讨论

1) 本研究应用 MSCA 法成功地分析了世界的动物、植物和微生物，不仅得到层次清晰、结构合理、符合学科要求的聚类结果，还能获得传统方法无法计算的多项指标，如总相似性系数、总相异性系数、相似性贡献率、相异性贡献率等。再次证明 MSCA 的数据挖掘能力明显优于传统聚类方法。

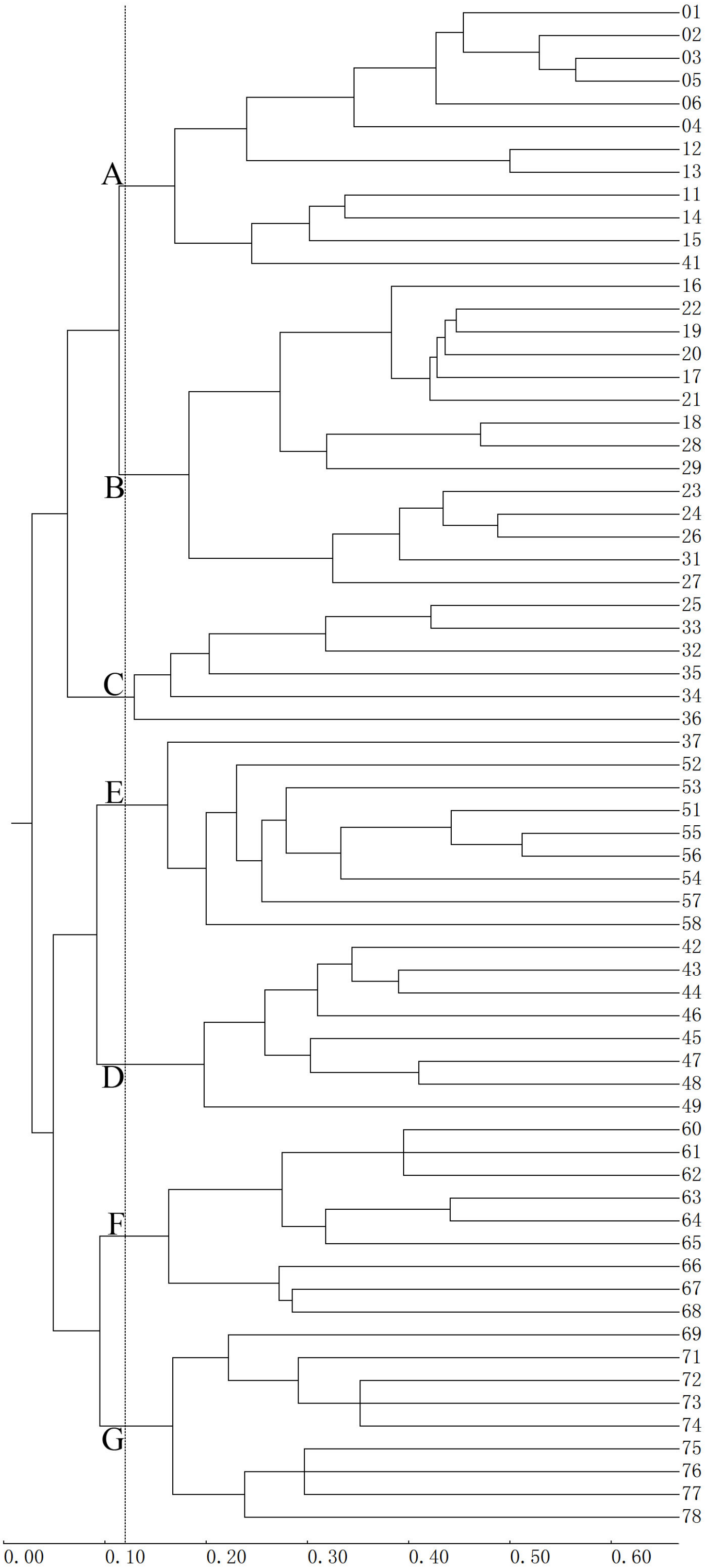


Figure 4. Clustering tree of species of mammal

图 4. 哺乳动物聚类图

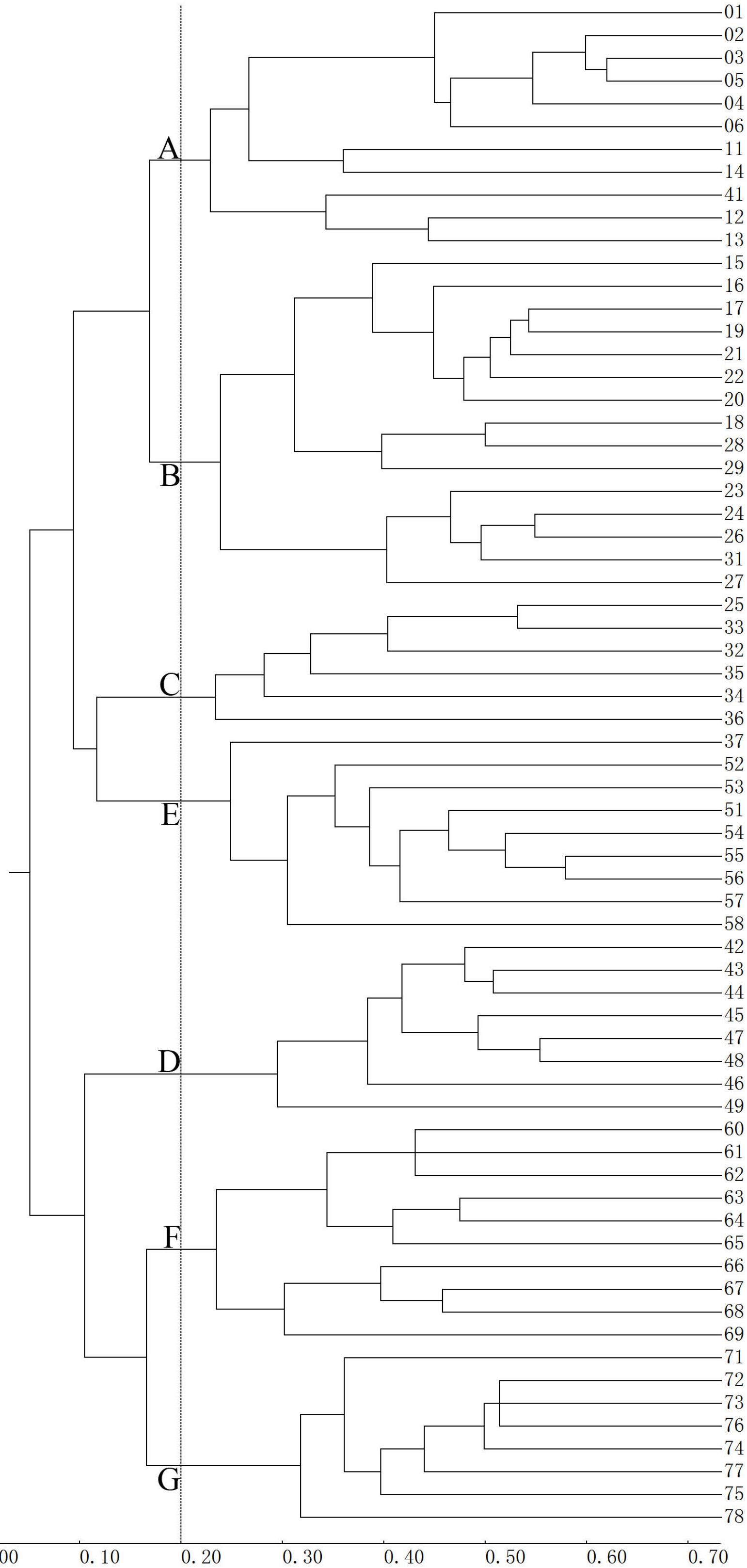


Figure 5. Clustering tree of mammal before 1876
图 5. 1876 年前哺乳动物聚类图

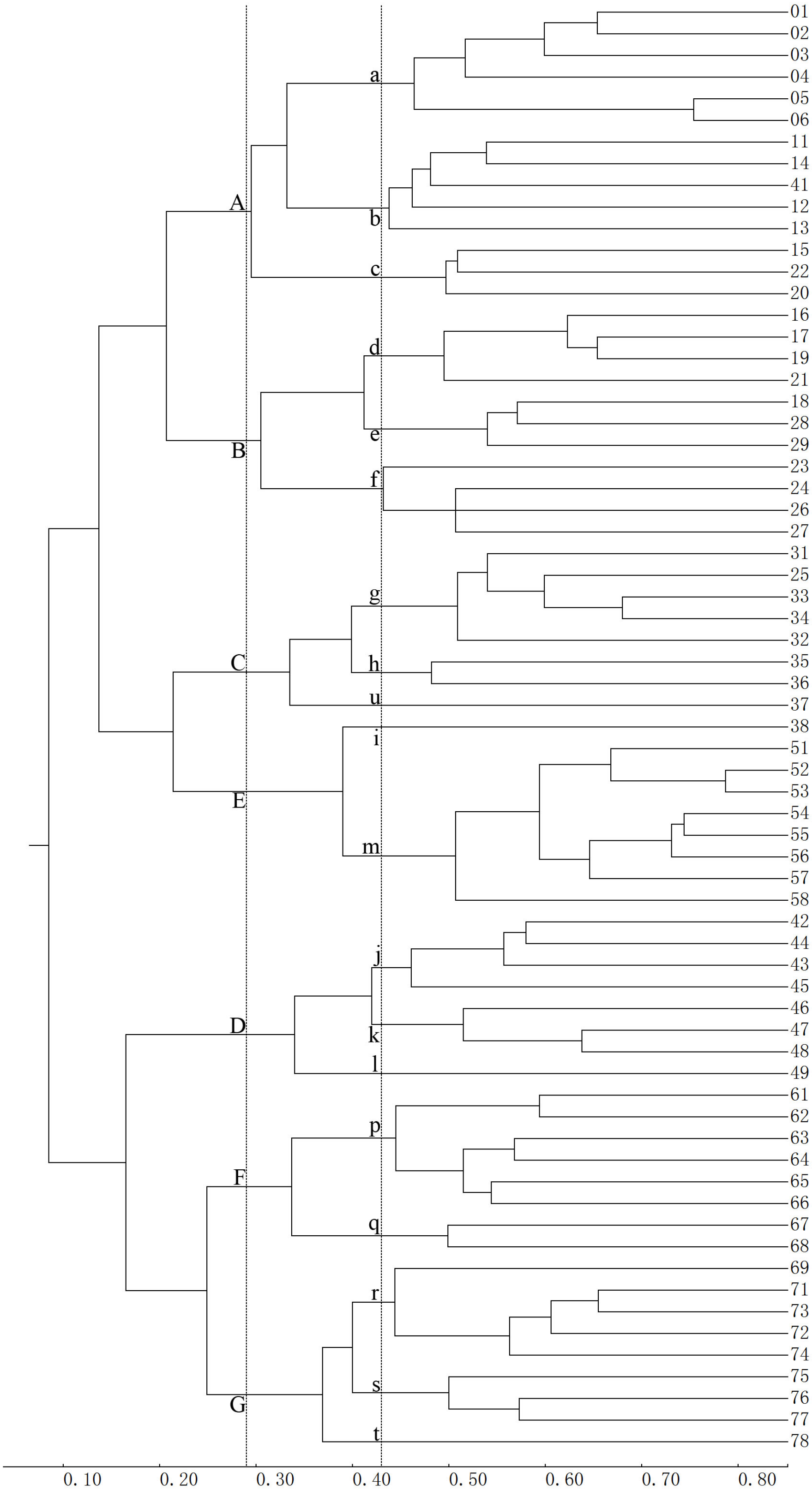


Figure 6. Dendrogram of chordata
图 6. 脊索动物聚类图

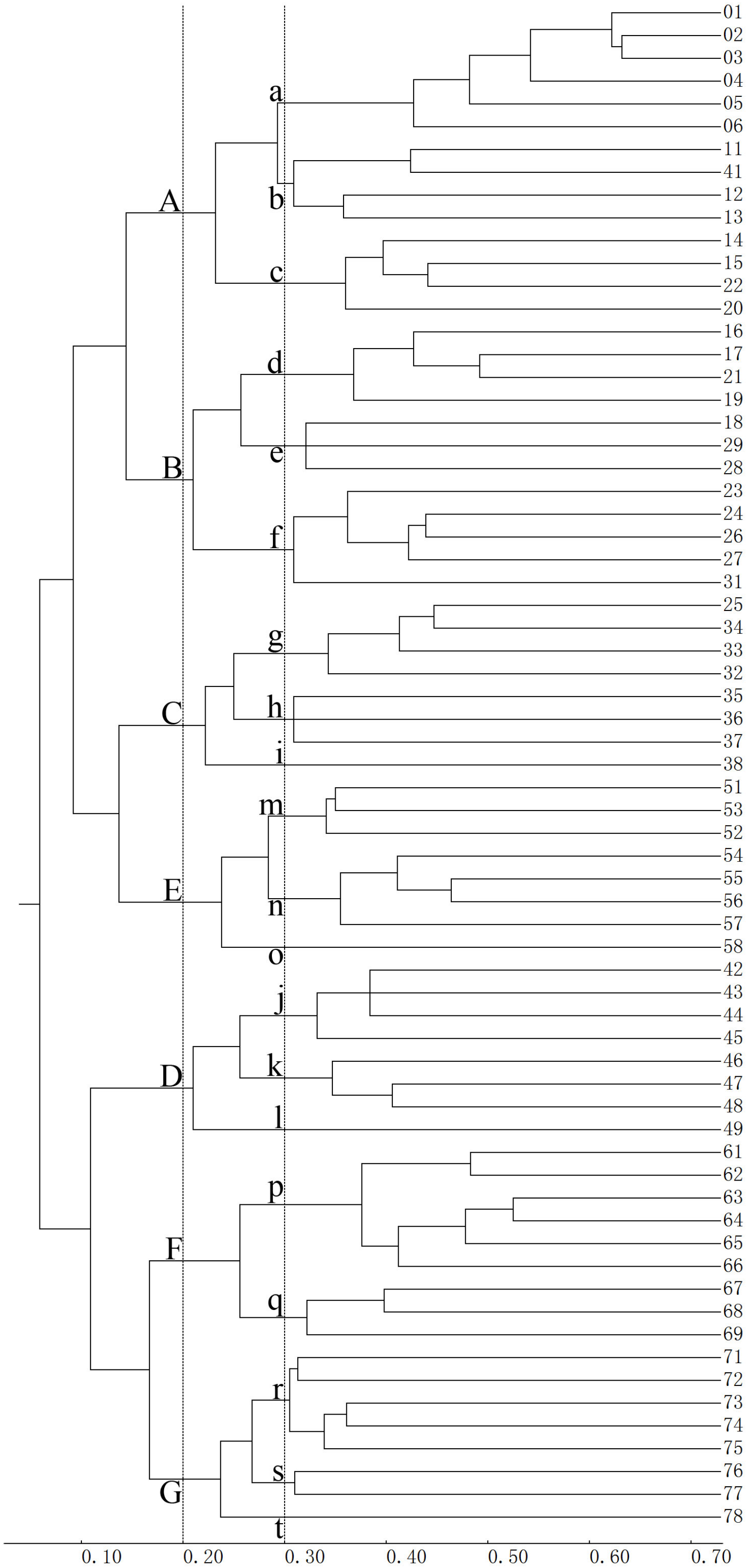


Figure 7. Dendrogram of arthropoda
图 7. 节肢动物聚类图

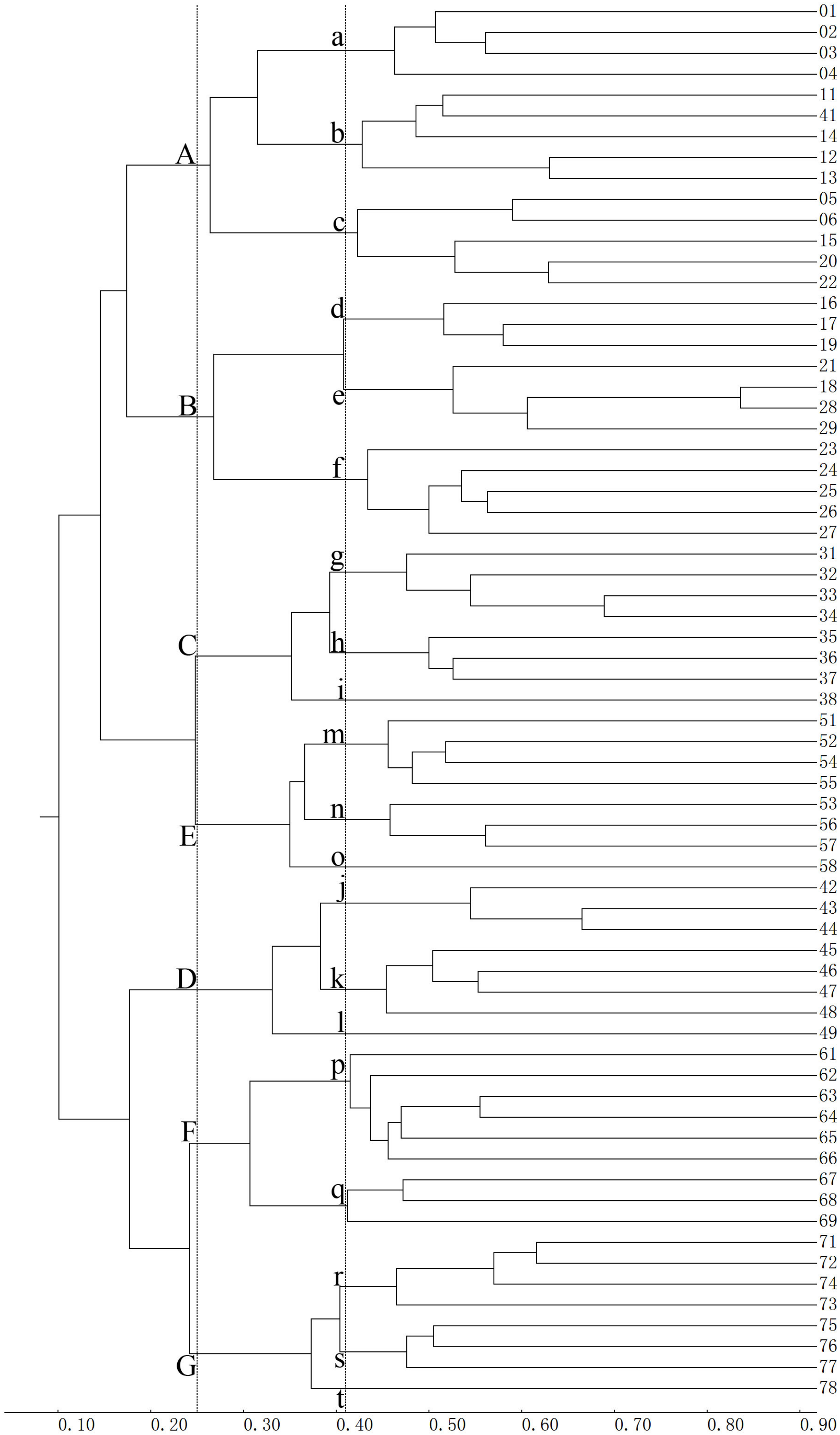


Figure 8. Dendrogram of magnoliophyta
图 8. 双子叶植物聚类图

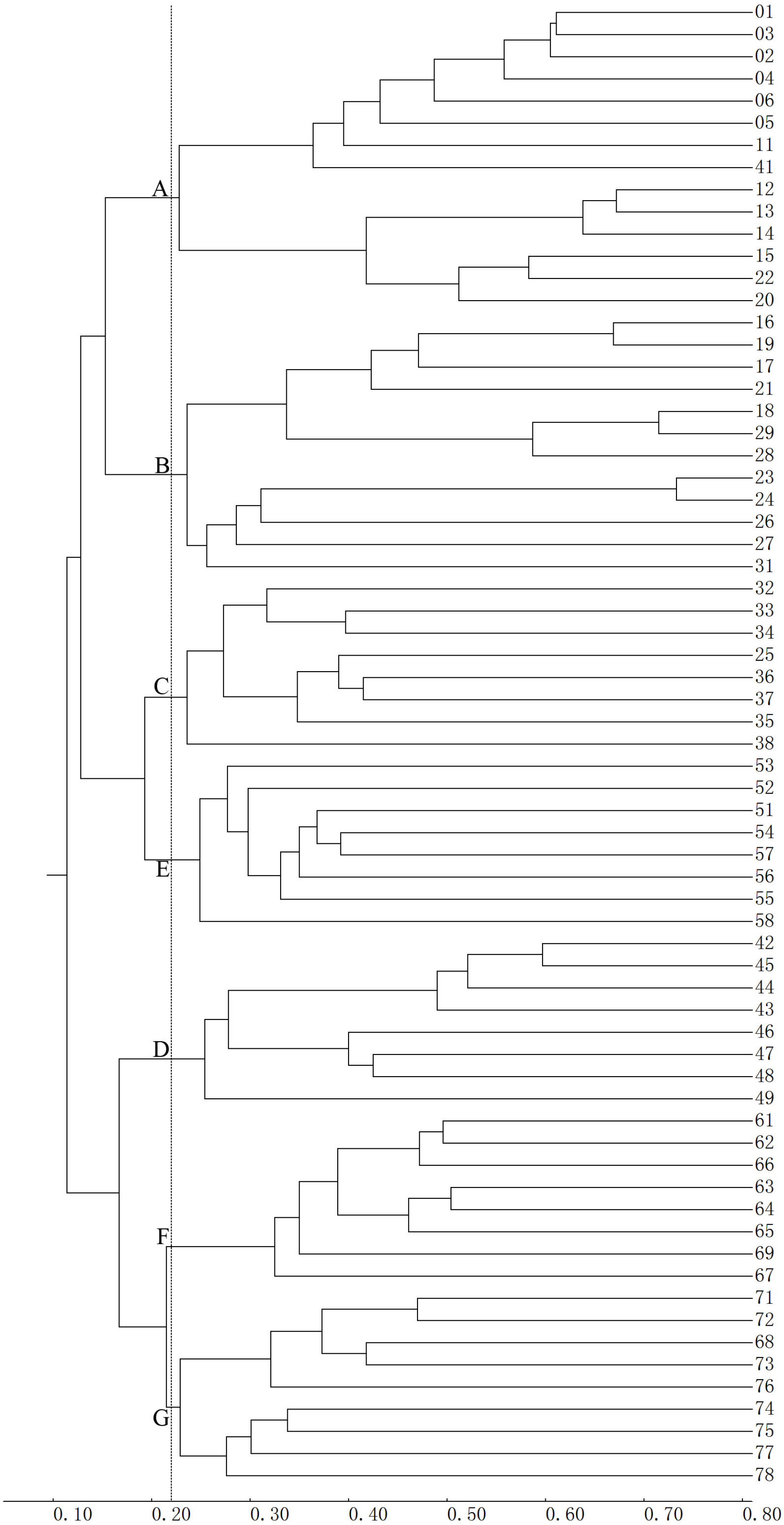


Figure 9. Dendrogram of ascomycota

图 9. 子囊菌聚类图

Table 4. The distribution of mammal in every BGU
表 4. 不同历史时期哺乳动物在各个 BGU 的分布

基础地理单元 BGU	哺乳动物种类 Mammalia		基础地理单元 BGU	哺乳动物种类 Mammalia		基础地理单元 BGU	哺乳动物种类 Mammalia	
	现有 present	Before 1876		现有 present	Before 1876		现有 present	Before 1876
01 北欧	60	59	28 朝鲜半岛	72	52	56 维多利亚	84	65
02 西欧	57	57	29 日本	106	61	57 塔斯马尼亚	37	31
03 中欧	100	84	31 喜马拉雅	227	169	58 新西兰	7	6
04 南欧	148	100	32 印度半岛	221	178	60 阿拉斯加	68	46
05 东欧	94	78	33 中南半岛	360	220	61 加拿大东部	77	61
06 欧洲俄罗斯	116	94	34 菲律宾	184	71	62 加拿大西部	129	94
11 中东	194	123	35 印度尼西亚	585	268	63 美东部山地	84	66
12 沙特阿拉伯	77	58	36 新几内亚	308	69	64 美中部平原	50	43
13 也门阿曼	67	46	37 太平洋岛屿	37	20	65 美中部丘陵	117	77
14 伊朗高原	211	149	41 北非	157	112	66 美西部山地	287	152
15 中亚	166	122	42 西非	375	200	67 墨西哥	479	201
16 西西伯利亚	61	56	43 中非	282	120	68 中美地区	297	146
17 东西伯利亚	139	109	44 刚果河流域	431	171	69 加勒比地区	110	50
18 乌苏里地区	106	80	45 东非	636	254	71 小安的列斯	110	67
19 蒙古	119	87	46 撒哈拉沙漠	109	79	72 圭亚那高原	329	161
20 阿尔泰山区	82	65	47 安哥拉地区	370	197	73 安第斯北段	613	236
21 中国东北	137	109	48 南非	256	179	74 亚马孙	347	178
22 中国西北	182	133	49 马达加斯加	178	73	75 巴西高原	296	187
23 青藏高原	241	166	51 西澳大利亚	90	64	76 玻利维亚	328	185
24 中国西南	311	224	52 北澳大利亚	49	25	77 阿根廷	340	174
25 中国华南	284	206	53 南澳大利亚	92	33	78 安第斯南端	113	68
26 中国中东部	287	191	54 昆士兰	164	94	BDR	13040	7555
27 中国台湾	99	71	55 新南威尔士	111	85	BBU	5412	2034

Table 5. Clustering results of every biota groups
表 5. 各生物类群的聚类分析结果

界 Kingdom	门 Phylum	纲 Class	目 Order	属数 BBU	总相似性系数 GSC	平均分布域 ADT	大群水平 Line LUC	大群 No. LUC	小群水平 Line SUC	小群 No. SUC
Animalia 动物界				133505	0.061	2.50	0.200	7	0.300	20
	Except incect 除昆虫以外的动物			29161	0.071	2.90	0.200	7	0.340	20
	Chordata 脊索动物门			6890	0.085	5.72	0.290	7	0.430	19
		Mammalia 哺乳纲		1374	0.086	5.67	0.240	7		
		Aves 鸟纲		2335	0.127	8.36	0.330	7	0.540	19

Continued

Osteichyes 硬骨鱼纲	1484	0.055	3.70	0.180	7		
Reptilia 爬行纲	1138	0.056	4.00	0.220	7		
Amphibia 两栖纲	539	0.048	3.53	0.190	7		
Arthropoda 节肢动物门	120379	0.059	2.34	0.200	7	0.300	20
Arachnida 蛛形纲	12269	0.055	1.73	0.180	7		
Araneae 蜘蛛目	4567	0.062	3.08	0.180	7		
Insecta 昆虫纲	104344	0.058	2.39	0.200	7	0.300	20
Hemiptera 半翅目	13,251	0.052	3.89	0.180	7	0.270	19
Coleoptera 鞘翅目	38,537	0.050	3.78	0.170	7	0.300	20
Diptera 双翅目	14002	0.076	5.52	0.190	7	0.270	20
Lepidoptera 鳞翅目	18051	0.058	4.40	0.200	7	0.260	18
Hymenoptera 膜翅目	8761	0.075	5.69	0.180	7	0.300	20
Other others 其它目	11739	0.051	3.86	0.200	7	0.300	19
Other classes 其它纲	3766	0.093	2.98	0.230	7		
Plantae 植物界	27092	0.112	4.63	0.270	7	0.400	20
Liliophyta 单子叶植物	3885	0.124	6.24	0.300	7	0.430	19
Aspargales 天门冬目	1596	0.094	4.86	0.260	7	0.390	19
Poales 禾本目	1258	0.158	8.44	0.350	7	0.500	19
Other orders 其它目	1031	0.124	5.69	0.250	8	0.400	20
Magnoliophyta 双子叶植物	20809	0.101	3.86	0.250	7	0.410	20
Asterales 菊目	1301	0.116	4.77	0.270	7	0.420	20
Caryophyllales 石竹	1666	0.099	3.70	0.230	7	0.400	19
Ericales 杜鹃花目	969	0.093	3.45	0.240	7	0.360	18
Fabales 豆目	1594	0.121	4.56	0.290	7	0.460	20
Gentianales 龙胆目	2026	0.080	3.40	0.230	8	0.380	20
Lamiales 唇形花目	2606	0.098	3.68	0.300	8	0.400	22
Other orders 其它目	10647	0.100	3.85	0.250	7	0.410	19
Other 11 small phylums 其它 11 小门	2398	0.167	8.63	0.310	7	0.410	16
Microorganism 菌物界	8556	0.125	4.80	0.195	7		
Fungi 真菌	7574	0.121	4.56	0.230	7		
Ascomycota 子囊菌	5286	0.114	4.18	0.220	7		

Note: BBU: basic biological unit; GSC: general similarity coefficient: ADT: average distributional territory; LUC: large unit crowd; SUC: small unit crowd.

2) 本研究所提出的几项生物分布特征从宏观角度解析了生物分布区形成的基础、原因以及进行地理区划应遵循的原则，为进一步总结生物分布规律、阐释形成机制提供了探讨途径和事实依据，丰富了生物地理学的理论内容。

3) 虽然人们对动、植物分布格局的一致性早有预期，但一直无从证实。本研究首次从多维度证明生态条件对生物分布格局影响的同质性将促进生物地理学科的发展，使生物地理区划这一游走在象牙塔里的幽灵变为人们得心应手的实用工具。

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