Distribution patterns and faunal characteristic of mammals on Hainan Island of China

Youhua CHEN[1,2]

[1] *College of Life Sciences, Wuhan University, P.R. China, 430072; e-mail: haydi@126.com*

[2] *Department of Zoology, University of British Columbia, B.C., Canada, V6T 1Z4*

Received 13 September 2007; Accepted 6 March 2009

A b s t r a c t . As one of the world's biodiversity hotspots, Hainan Island is widely recognized as a distinct biogeographical unit in zoogeography of China. The aim of this study is to analyze whether there are groups of mammalian assemblage that share similar geographical distributions (chorotypes) in Hainan Island and to reveal the faunal similarity between the island and its adjacent areas. Environmental correlations are also carried out to interpret the formation of these chorotypes. I employed cluster analysis with statistical test to detect chorotypes and then used logistic regression analysis to identify favourable environmental factors that potentially explained the distribution of each chorotype. Common species of Hainan Island shared by different Asian countries were gathered to infer the faunal relationship between Hainan Island and adjacent areas. Results showed that there were fourteen mammalian chorological patterns in Hainan Island; Hainan was close to Southern and Southeastern Asian countries based on their faunal similarity. Precipitation and temperature were the main factors driving the spatial patterns of mammals in Hainan.

Key words: chorotypes, environmental variables, faunal similarity

Introduction

Species distribution pattern is an important issue in the study of biogeography and ecology (B i r k s 1976), which aims to identify and group homogenous species that share similar geographical distribution (named as chorotypes) (M c C o y et al. 1986, M á r q u e z et al. 1997) because it could enrich our knowledge of local species diversity patterns. The underlying foundation of the chorotypes is that there is a hierarchical classification of the biota in studied areas (O w e n 1990, M á r q u e z et al. 1997). Chorological patterns of organisms could be identified through quantitative approaches, and often a cluster analysis is carried out (e.g. B i r k s 1976, B a i g ú n & F e r r i z 2003). However, despite of simple phenetic clustering methods, there are many studies (e.g. M á r q u e z et al. 1997, B á e z et al. 2005) published in recent years which have adapted the statistical tests (M c C o y et al. 1986). The method of M c C o y et al. (1986), which allows eliminating the interference of artificial forks in the dendrogram, makes chorological patterns identified effectively at the grounded statistical paradigm (M á r q u e z et al. 1997).

Hainan Island, the largest tropical island of China, is one of the hotspots in biodiversity network of China and the world (M y e r s et al. 2000, C h e n & B i 2007). It is situated at 18º9´~20º11´N and 108º~111º4´E and separated from Leizhou Peninsula by about 30 km distance. The island had a transitional climatic characteristic mixed with tropical and temperate weather conditions. Its topography has a feature that is high in middle ranges but low in peripheral areas. Most of the middle and southern parts are mountainous (http://www.dloer.gov.cn/ReadNews.asp?NewsID=356). The climatic conditions of Hainan Island differ from those of the other provinces of China, with higher temperature and precipitation. The representation of endemic vertebrate species in Hainan Island is fairly high comparing to other mainland areas of China. There are around 11 amphibians, 6 reptiles and 15 mammals endemic to the island (Shi & Meng 2001, Shi 2002). Most of these endemic species are named with the prefix "Hainan" (e.g. *Nomascus hainanus* or *Neohylomys hainanensis*). Studying species distribution of Hainan Island has many implications: 1) it is one of the hotspots globally (Myers et al. 2000); 2) it represents the tropical island geographical context and is located in the transitional zone between tropical and temporal zones in Northern Hemisphere (Zhang 1999); 3) biological invasions have become serious in the island due to tourism and international trade (www.chinabiodiversity.com). An analysis of ecological patterns of native fauna is important when responding to the faunal homogenization (Rahel 2000) brought by invasive species.

The chorological patterns of vertebrate assemblage are of considerable interest since they could refine biogeographical zonation (Márquez et al. 2001), reconstruct the regional development of fauna (Martynenko 2007) and infer the correlation between environmental factors and diversity patterns (Soares & Brito 2007). There are seldom attempts made to achieve the above goals for Hainan fauna, although some published works have been focused to the biodiversity inventories and distributional records (Zhao 1990, Shi & Meng 2001). Shi (2002) discussed the biogeographical zonation of amphibians; Gong et al. (2003) proposed the zoogeographic patterns of freshwater turtles in the island; Lu et al. (2005) discussed the diversity of lizards in the island, and Zhao et al. (2005) and Wang et al. (2005) carried out the field survey of terrestrial snakes and amphibians of the island, respectively. In contrast, in the present study we will try to address the following ecological questions: Are there significant clustering patterns of mammalian species in an isolated island? What is the association between these deductive patterns and surrounding environmental conditions? Could environmental variables explain these patterns? Which geographic regons are similar to Hainan Island according to their faunal composition?

Material and Methods

Data set

The distributional records of mammals in Hainan Island were retrieved and checked from CSIS (China Species Information Service: http://www.chinabiodiversity.com/) and previously published literature (Shi & Meng 2001, Zhang 2001, Wang 2003, Smith & Xie 2008). Fig. 1 shows the studied island and 19 administrative counties. I followed the recommendation of Márquez et al. (2001), which employed administrative counties as operational geographical units (OGUs). Although Qiongshan has been incorporated into Haikou, I still treat it as an independent geographic operative unit following the work of Chen (2008). The list of studied species and their occurrence in OUGs is showed in Appendix.

Cluster analysis with statistical tests

We followed the methodology firstly proposed by McCoy et al. (1986). This method could identify those significant clusters in a dendrogram using statistical test. In detail, I carried out the analysis using the following steps.

Fig. 1. 19 operational geographical units (OGUs) of Hainan Island.

The similarity coefficient was estimated using Baroni-Urbani & Buser's (1976) binary similarity measure. I then calculated the significance of the similarities using the probability table of Baroni-Urbani & Buser (1976), because this procedure allows statistical independence between observed and expected values. In this way the similarity matrix was transformed into a matrix of significant similarities in which we replaced the values of BUB similarity index with '+', '-' and '0' signs according to whether the index value was significantly higher than that expected at random, significantly lower, or not significantly different respectively.

I implemented the UPGMA (Unweighted Pair Group Method Using the Arithmetic Averaging) for classifying species. Sequentially, a series of submatrixes of signs were constructed that only includes the species of the evaluated node in the dendrogram, which could be divided into three zones: zone A and zone B, which correspond to each group of species that the node separates respectively, and the zone A×B, corresponding to the intersection between the zones A and B. Based on the proportions of the different signs "+", "-", "0" in the three zones, I could obtain the following parameters that are necessary to distinguish the groups comparing those that are generated randomly in the analysis.

The parameters DW (A×A), DW (B×B) provide information on how large the significant positive similarity (+) is in the zones A×A or B×B, while not in the zone A×

B. The parameter DS estimates if the significant negative similarity proportion (-) tends to concentrate in the zone A×B, but not in A×A or in B×B. The independence test (G-test) was carried out to appraise the statistical significance of each node in the dendrogram, where the distribution of the signs "+", "-" and "0" between the three zones is constructed carefully to obtain the parameters GS and GW. If GS is significant and DS > 0, there is a strong segregation between the groups that separate the node. On the contrary, if GW is significant and DW > 0, the segregation is weak (M c C o y et al. 1986). The cluster analysis was performed using the software MVSP 3.13i (Kovach Computing Services, http://www.kovcomp.com/). The remaining statistical steps were completed by a VBA (visual basic for application) program entitled 'ClusteringTest', which was developed by the author and is available upon request.

Environmental correlation

Logistic regressions were performed to test the possible relationships of the chorotypes with environmental factors (S o k a l & R o h l f 1995, B á e z et al. 2005). The fitted degree of each environmental factor with the distribution of the chorotype is measured by χ^2-test. Twenty-two environmental factors were used, which were collected from local climatic monitoring stations. All the variables included annual mean temperature, mean monthly temperature range, isothermality, temperature seasonality, maximum temperature of warmest month, minimum temperature of coldest month, temperature annual range, mean temperature of wettest quarter, mean temperature of driest quarter, mean temperature of warmest quarter, mean temperature of coldest quarter, annual precipitation, precipitation of wettest month, precipitation of driest month, precipitation seasonality, precipitation of wettest quarter, precipitation of driest quarter, precipitation of warmest quarter, precipitation of coldest quarter, longitude, latitude and altitude.

Faunal similarity with adjacent regions

A mammalian faunal similarity analysis was carried out to compare the mammalian distribution in Hainan Island with adjacent south, southeastern, and eastern Asian countries. The distributional data outside of China for each mammal in Hainan were examined through the database of Mammal Species of the World (MSW; http://vertebrates.si.edu/mammals/msw/).

Results

Based on the cluster analysis with statistical test performed in all 75 species, 69 species could be divided into 14 chorotypes of mammals in Hainan Island. The test results can be found in the dendrogram shown in Fig. 2. The maps of each chorotype are in Fig. 3. The summary of all data resulting from the statistical tests is shown in Table 1. Six species *Martes flavigula hainana*, *Rattus norvegicus, Tamiops swinhoei hainanus, Niviventer confucianus, Pipistrellus coromandra, Herpestes javanicus* did not show geographical similarity with their counterparts because their DW ≤ 0.

The detailed chorotypes and their species composition and geographical extensions were differentiated as follows: Chorotype 1 contained three species, *Cervus eldi hainanus, Hypsugo pulveratus,* and *Crocidura rapax*. Most of them occurred in westernmost area Dongfang with Baoting in the middle part of island. Mean temperature of warmest quarter

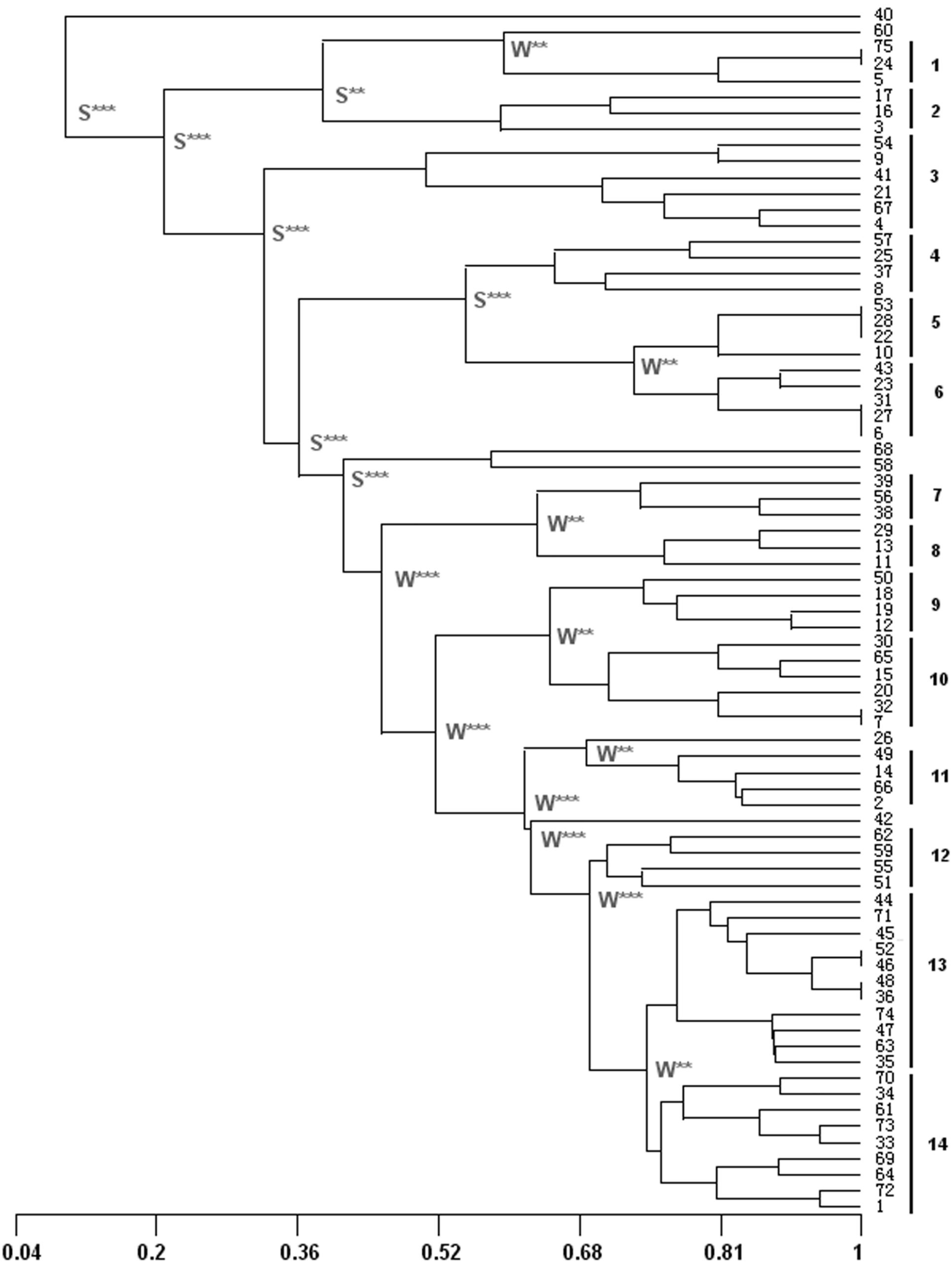

Fig. 2. The 14 chorotypes delimited from the species dendrogram of cluster analysis with statistical test. S*** and S** depicts the group was divided by strong segregation with P<0.001 and P<0.01 respectively, W*** and W** depicts the group was divided by weak segregation with P<0.001 and P<0.01 respectively. The species represented by the numbers can be found in Appendix.

(χ^2=4.528, P<0.05), precipitation seasonality (χ^2=4.623, P<0.05), precipitation of driest quarter (χ^2=3.915, P<0.05), precipitation of coldest quarter (χ^2=4.3734, P<0.05) were the factors that shape the joint distribution of species within this chorotype. The values of these

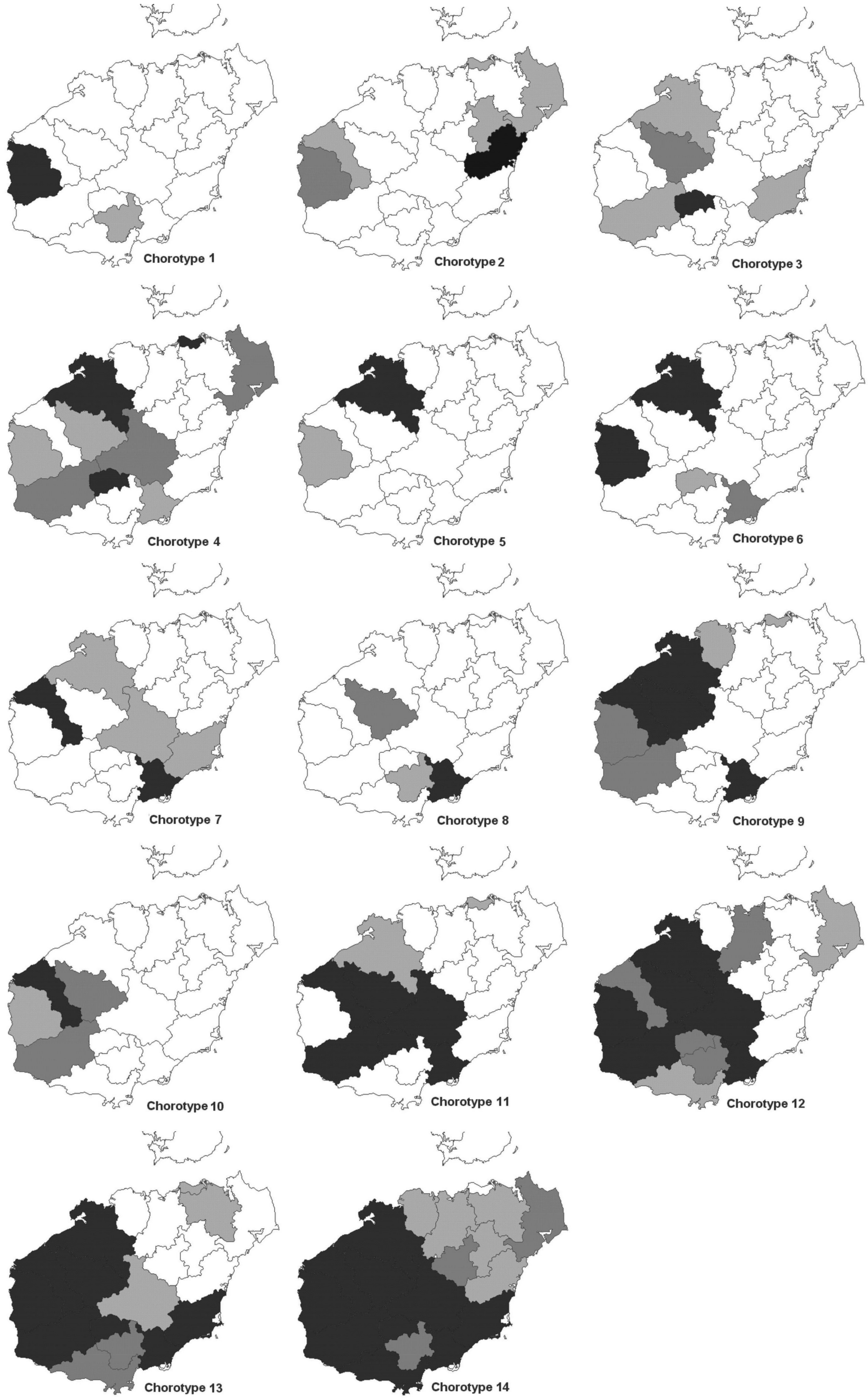

Fig. 3. The 14 chorotypes among the mammals of Hainan Island corresponding to the species dendrogram. The three grey colors from light to dark represent the areas that contain species percentage of 30%, 60% and 100% of the chorotype respectively.

Table 1. Significant segregation between groups of species at each node in the dendrogram generated by program 'ClusteringTest'. **P<0.05, ***P<0.001, n.s., no significance. GW and GS indicate weak segregation and strong segregation between the groups, respectively. DW(A×A) and DW(B×B) quantify the internal homogeneity of each group analyzed. DW and DS quantify the value of each boundary.

Group A	Group B	DW (A×A)	DW (B×B)	DS	GW	*P*	GS	*P*
40	60-1	0	-0.060	0.347	28.857	***	484.100	***
60-3	54-1	0.046	-0.001	0.109	104.325	***	992.339	***
54-4	57-1	0.324	0.038	0.024	70.087	***	511.157	***
57-6	68-1	0.395	0.194	0.153	209.002	***	405.890	***
68-58	39-1	-0.02	0.267	0.162	57.296	***	124.976	***
39-11	50-1	0.423	0.283	-0.001	107.519	***	74.477	***
50-7	26-1	0.422	0.393	-0.074	190.829	***	27.165	***
26-2	42-1	0.339	0.360	-0.235	90.160	***	0	n.s.
42	62-1	-0.216	0.399	-0.216	23.299	***	0	n.s.
62-51	44-1	0.121	0.235	-0.434	47.181	***	0	n.s.
44-35	70-1	0.047	0.040	-0.647	6.498	**	0	n.s.
26	49-2	-0.212	0.495	-0.212	7.719	**	0	n.s.
50-12	30-7	0.299	0.216	-0.408	8.245	**	1.14E-13	n.s.
39-38	29-11	0.409	0.409	-0.298	8.733	**	0	n.s.
53-10	43-6	0.134	0.134	-0.573	6.518	**	0	n.s.
54-9	41-4	0.380	0.313	-0.103	3.864	**	2.783	**
60	75-5	0	0.707	0	8.318	**	0	n.s.
57-8	53-6	0.313	0.518	-0.134	38.219	***	0	n.s.
60-5	17-3	0.261	0.143	0.1467	1.949	n.s.	5.174	**

precipitation attributes in the distributional areas of this chorotype are significantly smaller than those of other sites.

Chorotype 2 contained three species, *Kerivoula picta, Hipposideros pomona,* and *Suncus murinus*, and included two western areas and several northeastern areas. No significant variables interpreted this chorotype.

Chorotype 3 contained six species, i.e. *Chiropodomys gliroides, Rhinolophus luctus spureus, Mustela kat2hiah, Myotis davidii, Hylopetes alboniger* and *Crocidura horsfieldii*. The range was from middle mountainous areas to western dry areas, and it was insignificantly correlated with isothermality. No significant environmental variables were related to this chorotype. Mean month temperature range (χ^2=4.157, P<0.05) and isothermality (χ^2=9.659, P<0.005) were the two factors associated with the distribution of this chorotype.

Chorotype 4 contained four species, *Rattus rattus, Pipistrellus pipistrellus, Lutra lutra,* and *Cynopterus sphinx*, and it included most areas from middle to west, with two northern areas. No significant environmental factors interpreted the distribution of chorotype 4.

Chorotype 5 contained four species: *Rattus andamanensis*, *Scotophilus kuhlii, Myotis daubentonii,* and *Rhinolophus blythii*. The joint distribution of this chorotype included two western areas, Danzhou and Dongfang. Mean month temperature range (χ^2=5.069, P<0.05), mean temperature of coldest month (χ^2=4.163, P<0.05), temperature annual range (χ^2=5.598, P<0.05) and mean temperature of wettest quarter (χ^2=4.496, P<0.05) were the four factors correlated with the distribution of this chorotype.

Chorotype 6 contained five species, *Herpestes urva, Pipistrellus ceylonicus, Chaerophon plicatus, Scotophilus heathii,* and *Crocidura attenuate*. This chorotype overlapped with the chorotype 5 completely, and two southern areas partly. No significant environmental factors were associated with this chorotype.

Chorotype 7 contained three species and compassed the central transition areas at the crossing between southwestern part and northeastern part of the island associated with isothermality. The three species were *Melogale moschata, Niviventer coninga,* and *Aonyx cinerea*. Isothermality (χ^2=4.261, P<0.05) was the only factor affecting the distribution range of this chorotype.

Chorotype 8 mainly included three areas from western to southern part of the island. Related environmental factors were isothermality. It comprised *Scotomanes ornatus, Coelops frithii,* and *Rhinolophus sinicus*. Isothermality (χ^2=6.231, P<0.05) was the only factor associated with distribution of this chorotye.

Chorotype 9 covered most of the western coastal part of the island with four species, *Lepus hainanus, Miniopterus schreibersii, M. pusillus,* and *Rhinolophus affinis*. Annual mean temperature (χ^2=4.024, P<0.05), mean temperature of warmest quarter (χ^2=357, P<0.05), precipitation of driest month (χ^2=5.874, P<0.05), precipitation seasonality (χ^2=6.322, P<0.05), precipitation of driest quarter (χ^2=6.792, P<0.05), precipitation of coldest quarter (χ^2=5.843, P<0.05), longitude (χ^2=4.384, P<0.05) were indicative for the distributional range of this chorotype.

Chorotype 10 included the western dry areas and contained six species, *Taphozous melanopogon, Belomys pearsonii, Hipposideros larvatus, Myotis blythii, Nomascus concolor,* and *Rousettus leschenaulti*. Precipitation of driest month (χ^2=7.133, P<0.01), precipitation seasonality (χ^2=7.628, P<0.01), precipitation of driest quarter (χ^2=7.503, P<0.01), precipitation of coldest quarter (χ^2=7.722, P<0.01), longitude (χ^2=17.227, P=0.00003) were the factors affecting the distribution of chorotype 10, among which longitude had the best significant fit with this chorotype.

Chorotype 11 covered middle mountainous areas, extending to western costal areas and included *Neofelis nebulosa, Hipposideros armiger, Hylopetes phayrei,* and *Neohylomys hainanensis*. Mean temperature of warmest month (χ^2=4.608, P<0.05), mean temperature of warmest quarter (χ^2=5.813, P<0.05), precipitation of driest month (χ^2=3.885, P<0.05) were the factors that interpreted its distribution.

Chorotype 12 encompassed most of western areas and southern areas, and included four species, *Rattus nitidus, Niviventer fulvescens, Mus musculus,* and *Hystrix brachyuran*. Isothermality (χ^2=6.226, P<0.05), mean temperature of warmest month (χ^2=6.061, P<0.05), precipitation of driest month (χ^2=11.577, P<0.001), precipitation seasonality (χ^2=10.747, P<0.005), precipitation of driest quarter (χ^2=10.462, P<0.005), precipitation of coldest month (χ^2=10.536, P<0.005), longitude (χ^2=7.953, P<0.005), latitude (χ^2=5.426, P<0.05) were associated with the distribution of this chorotype.

Chorotype 13 covered most of western and southern areas similarly as the chorotype 12, with additional two northern areas. Eleven taxa were identified within this chorotype, *Viverra zibetha, Dremomys rufigenis, Viverricula indica, Atherurus macrourus, Paradoxurus hermaphroditus, Felis bengalensis hainana, Ursus thibetanus, Cervus unicolor hainana, Paguma larvata hainana, Rattus rattoides,* and *Manis pentadactyla pusillus*. Related environmental factors were isothermality (χ^2=3.996, P<0.05), mean temperature of warmest month (χ^2=8.738, P<0.001), precipitation of driest month (χ^2=9.727, P<0.001), precipitation seasonality (χ^2=12.833, P<0.0005), precipitation of driest quarter (χ^2=8.072, P<0.005), precipitation of coldest quarter (χ^2=7.93, P<0.005), latitude (χ^2=5.862, P<0.05), longitude (χ^2=5.003, P<0.05) were correlated with this chorotype, and precipitation seasonality was the most important factor affecting its distribution.

Chorotype 14 covered most areas of the island, excepting Haikou. The influencing environmental variables were annual precipitation and longitude. The species' distributional centers were concentrated in western and southern areas. Nine species were associated with this chorotype, i.e. *Callosciurus erythraeus, Tupaia belangeri, Rattus tanezumi, Muntiacus nigripes, Nomascus hainanus, Ratufa bicolor, Petaurista hainana, Sus scrofa,* and *Mogera coreana*. Isothermality (χ^2=7.397, P<0.001), month of wettest quarter (χ^2=6.973; P<0.001), month of driest quarter (χ^2=4.914, P<0.05), month of coldest quarter (χ^2=5.179, P<0.05), latitude (χ^2=6.470, P<0.05) and mean month temperature range (χ^2=6.294, P<0.05) were significantly correlated with the distribution of this chorotype.

Discussion

Distribution patterns of mammals in Hainan Island

Hainan Island is an island with high species diversity and endemism within China and even at the global scale (Zhang 1999, Gong et al. 2003). The hitherto records showed that the number of amphibians, reptiles, birds and mammals of Hainan Island achieved the proportion of 18.8%, 33%, 30.7% and 18.6% of the whole fauna of China, respectively (http://www.ecoprov.com/ReadNews.asp?NewsID=16). Such a high species richness was recorded in only few Chinese provinces. However, compared to the area size, Hainan Island (33 979 km^2) is considerably smaller than other species-rich provinces (383 978 km^2 for Yunnan, 484 310 km^2 for Sichuan).

Although there are some additionally reported species (e.g. Li et al. 2006), the 75 species I used for the analysis is enough to infer the structure of chorotypes of the island. Except of six species, others were identified to constitute 14 chorotypes in the island using a hierarchical clustering approach. The identification of chorotypes can reveal the relationships between the suitable ecological factors and the distribution patterns. The present study showed that geographical overlapping exists among chorotypes. For example, except of the widely distributed chorotype 14, the chorotypes 4, 13, 9 overlapped with the chorotypes 6, 11, 10 respectively. The overlapping of the chorotypes indicated the existence of hierarchical clustering of species distribution in the island in a non-random way (Márquez et al. 1997). Regarding the distributional boundaries of these 14 chorotypes, most have distributional biases in the southwestern part of the island, such as chorotypes 9, 10 and 11 (Fig. 3). A few chorotypes (e.g. 2, 4, 12) extend into the northernmost parts of the island.

The areas with overlapping chorotypes have often high species richness (e.g. Danzhou (47 species), Dongfang (40 species), Baisha (43 species), Ledong (39 species), and Changjiang (43 species) (Fig. 3). These areas are situated in the southwestern and middle parts of the island. Considering the geomorphological and meteorological characteristics of the island, it is evident that it is a local species diversity hotspot. *Nomascus hainanus, Neohylomys hainanens and Cervus eldi hainanus* are the typical mammals occurring exclusively this hotspot. This recognition was emphasized in some recent works (Jiang et al. 2002, Wang et al. 2006).

Temperature and precipitation were the main factors shaping the distribution of mammals in Hainan. The results of logistic regression showed that most of the chorotypes were associated with these two factors. For example, chorotype 1 was mainly associated with precipitation; chorotype 3, 5, 7 and 8 were principally correlated with temperature attributes;

other chorotypes could also be interpreted by additional factors such as latitude and longitude. Elevation itself did not explain any chorotypes. In addition, some variables may explain chorotypes specifically. e.g., mean temperature of coldest month, mean temperature of wettest quarter and temperature annual range correlated only with the chorotype 5; month of wettest quarter, month of driest quarter and month of coldest quarter interpreted only the chorotype 14.

Faunal similarity with adjacent areas

A geographical map exhibiting the faunal associations of Hainan Island with adjacent areas is shown in Fig. 4. Apparently, the fauna of Hainan is more related to that occurring in the Indo-China Peninsula whereas it is not close to those from the Malaya and Korean Peninsulas. The results showed that the connectivity of faunal similarity among different areas would be more similar if they were located in the same latitudinal range. The biogeography patterns of mammals in Hainan Island are mainly related to the fauna of Oriental Region, not Palaearctic and/or Australasian Regions.

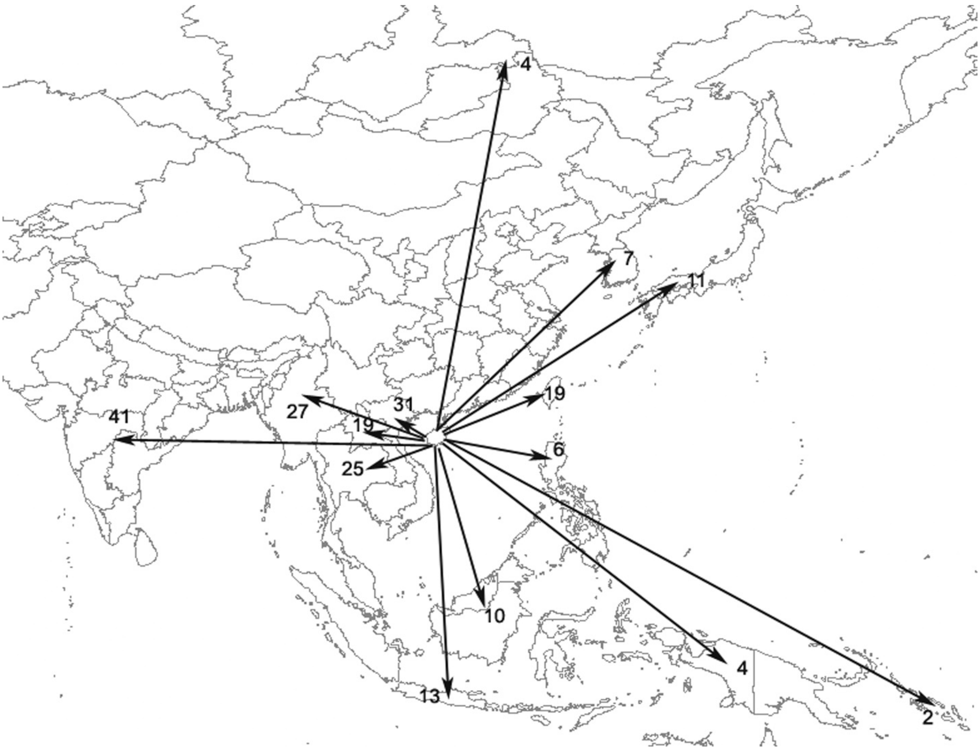

Fig. 4. The faunal association of Hainan Island with adjacent Asian areas. The number at the end of each line depicts the shared species number of the region with Hainan Island.

Acknowledgements

The author would express sincere gratitude to Ken Kinman for his hard work on polishing the earlier versions of the manuscript; Susana Gómez-González and A. L. Márquez for providing lots of helps on the analytical techniques; Antonio Flores-Moya for kindly posting one of his papers and Xingxing Man for collecting some data. Two reviewers and editors are also apprecipated for providing insightful comments.

LITERATURE

Báez J.C., Real R., Vargas J.M. & Flores-Moya A. 2005: Chorotypes of seaweeds from the western Mediterranean Sea and the Adriatic Sea: An analysis based on the genera *Audouinella* (Rhodophyta), *Cystoseira* (Phaeophyceae) and *Cladophora* (Chlorophyta). *Phycol. Res. 53: 255–265.*

Baigún C. & Ferriz R. 2003: Distribution patterns of native freshwater fishes in Patagonia (Argentina). *Org. Divers. Evol. 3: 151–159.*

Baroni-Urbani C. & Busher M.W. 1976: Similarity of binary data. *Syst. Zool. 24: 165–178.*

Birks H.J.B. 1976: The distribution of European pteridophytes: a numerical analysis. *New Phytol. 77: 257–287.*

Chen Y.H. 2008: Avian biogeography and conservation on Hainan Island, China. *Zool. Sci. 25: 59–67.*

Chen Y.H. & Bi J.F. 2007: Biogeography and hotspots of amphibian species of China: implications to reserve selection and conservation. *Curr. Sci. 92: 480–489.*

Gong S.P., Xu R.M. & Shi H.T. 2003: Zoogeography and conservation priority of hard-shelled freshwater turtles on Hainan Island. *Chinese J. Zool. 38: 68–71.*

Jiang Y.X., Wang B.S., Zang R.G., Jin J.H. & Lian W.B. 2002: Biodiversity and evolution mechanisms of tropical forests in Hainan Island. *Science Press, Beijing. (in Chinese)*

Li Y., Wu Y. & Chen Z. 2006: A new record of Rickett's big-footed bat *Myotis ricketti* in Hainan Island of China. *Acta Theriol. Sin. 26: 211–212. (in Chinese)*

Lu S.Q., Wang L.J. & Shi H.T. 2005: Diversity of lizards in Hainan Island. *Sichuan J. Zool. 24: 312–314.*

Márquez A.L., Real R. & Vargas J.M. 2001: Methods for comparison of biotic regionalizations: the case of pteridophytes in the Iberian Peninsula. *Ecography 24: 650–670.*

Márquez A.L., Real R., Vargas J.M. & Salvo A.E. 1997: On identifying common distribution patterns and their causal factors: A probabilistic method applied to pteridophytes in the Iberian Peninsula. *J. Biogeogr. 24: 613–631.*

Martynenko A. 2007: Butterflies (Lepidoptera, Diurna) in the high-mountain southeastern Russia. *Biol. Bull. 34: 20–27.*

McCoy E.D., Bell S.S. & Walters K. 1986: Identifying biotic boundaries along environmental gradients. *Ecology 67: 749–759.*

Myers N., Mittermeier R.A., Mittermeier C.G., da Fonseca G.A.B. & Kent J. 2000: Biodiversity hotspots for conservation priorities. *Nature 403: 853–858.*

Owen J.G. 1990: An analysis of the spatial structure of mammalian distribution patterns in Texas. *Ecology 71: 1823–1832.*

Rahel F.J. 2000: Homogenization of fish faunas across the United States. *Science 288: 854–856.*

Soares C. & Brito J.C. 2007: Environmental correlates for species richness among amphibians and reptiles in a climate transition area. *Biodivers. Conserv. 16: 1087–1102.*

Sokal R.R. & Rohlf F.J. 1995: Biometry. *W.H. Freeman and Company, New York.*

Shi H.T. 2002: Fauna and geographical delimitation of amphibians of Hainan Island. *Sichuan J. Zool. 21: 174–176.*

Shi H.T. & Meng J.L. 2001: An identification guide to Hainan terrestrial vertebrate. *Hainan Press, Haikou. (in Chinese)*

Smith A.T. & Xie Y. 2008: A guide to the mammals of China. *Princeton University Press, Princeton and Oxford.*

Wang F.G., Qin X.S., Chen H.F., Zhang R.J., Liu D.M. & Xing F.U. 2006: Endemic plants in limestone region on Hainan Island. *J. Trop. Subtrop. Bot. 14: 45–54.*

Wang L.J., Shi H.T., Hong M.L., Xiong Y., Wang J.C. & Liang W. 2005: Surveys of amphibians of Hainan with measurement of rare, especially endemic species. *Sichuan J. Zool. 24: 301–308.*

Wang Y.X. 2003: A complete checklists of mammal species and subspecies in China: A taxonomic and geographic reference. *China Forestry Publishing House, Beijing. (in Chinese)*

Zhang R.Z. 1999: Zoogeography of China. *Science Press, Beijing. (in Chinese)*

Zhang Z.Q. 2001: Fauna of China. Synopsis-Mammals of China: a faunistic analysis and checklist. *Magnolia Press, Auckland.*

Zhao E.M. 1990: Herpetofauna and zoogeography of Hainan Island. *China Forestry Publishing House, Beijing. (in Chinese)*

Zhao E.M., Zhao H., Shi H.T. & Wang L.J. 2005: Surveys of terrestrial snakes on Hainan. *Sichuan J. Zool. 24: 315–322.*

Appendix. 75 mammalian species list of Hainan Island used in this study and its presence (1) /absence (0) in 19 OGUs (endemic species are marked in bold). Code of each OGU was: 1-Haikou; 2-Qiongshan; 3-Chengmai; 4-Lingao; 5-Danzhou; 6-Wenchang; 7-Dingan; 8-Qionghai; 9-Wanning; 10-Lingshui; 11-Sanya; 12-Ledong; 13-Dongfang; 14-Changjiang; 15-Baisha; 16-Tunchang; 17-Qiongzhong; 18-Wuzhishan; 19-Baoting.

No.	Species List	Operative Geographical Unit																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	*Mogera coreana*	0	0	0	0	1	0	1	0	1	1	1	1	0	1	1	1	1	1	1
2	***Neohylomys hainanensis***	0	0	0	0	0	0	0	0	0	1	0	1	0	0	1	0	1	1	0
3	*Suncus murinus*	1	0	0	0	0	1	1	1	0	0	0	0	1	0	0	0	0	0	0
4	*Crocidura horsfieldii*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0
5	*Crocidura rapax*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
6	*Crocidura attenuata*	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
7	*Rousettus leschenaulti*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
8	*Cynopterus sphinx*	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	***Rhinolophus luctus spureus***	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0
10	*Rhinolophus blythi*	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
11	*Rhinolophus sinicus*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
12	*Rhinolophus affinis*	0	0	0	0	1	0	0	0	0	1	0	1	0	1	1	0	0	0	0
13	*Coelops frithii*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
14	*Hipposideros armiger*	0	0	0	0	0	0	0	0	0	1	0	1	0	1	1	0	0	1	0
15	*Hipposideros larvatus*	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0
16	*Hipposideros pomona*	0	0	0	0	0	0	0	1	0	0	0	0	1	1	0	0	0	0	0
17	*Kerivoula picta*	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
18	*Miniopterus schreibersii*	0	0	0	0	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0
19	*Miniopterus pusillus*	0	0	0	0	1	0	0	0	0	1	0	0	0	1	1	0	0	0	0
20	*Myotis blythii*	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
21	*Myotis davidii*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
22	*Myotis daubentonii*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	*Pipistrellus ceylonicus*	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0
24	*Hypsugo pulveratus*	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
25	*Pipistrellus pipistrellus*	1	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	1	1	0
26	*Pipistrellus coromandra*	0	0	0	0	0	0	0	1	0	0	0	1	0	1	1	0	1	0	0
27	*Scotophilus heathii*	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
28	*Scotophilus kuhlii*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
29	*Scotomanes ornatus*	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1
30	*Taphozous melanopogon*	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
31	*Chaerophon plicatus*	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
32	*Macaca mulatta*	0	0	0	0	1	1	0	0	1	1	1	1	1	1	1	0	1	0	1
33	***Nomascus hainanus***	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
34	*Tupaia belangeri*	0	1	0	1	1	1	0	0	1	1	0	1	1	1	1	1	1	1	0
35	***Manis pentadactyla pusillus***	1	0	0	0	1	0	0	0	1	1	1	1	1	1	1	0	0	1	0
36	*Ursus thibetanus*	0	0	0	0	1	0	0	0	1	1	0	1	1	1	1	0	0	1	1
37	*Lutra lutra*	1	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	1	0
38	*Aonyx cinerea*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0
39	*Melogale moschata*	0	0	0	0	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0
40	***Martes flavigula hainana***	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
41	*Mustela kathiah*	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	1	1
42	*Herpestes javanicus*	0	1	0	0	1	0	0	1	1	0	0	1	0	1	1	0	0	1	0
43	*Herpestes urva*	0	0	0	0	1	0	0	0	0	1	0	0	1	0	0	0	0	1	0

44	*Viverra zibetha*	0	0	0	0	1	0	0	0	1	1	0	0	1	0	1	0	0	1	1
45	*Viverricula indica*	0	1	0	0	1	0	0	0	1	1	0	1	1	1	1	0	1	1	1
46	*Paradoxurus*	0	0	0	0	1	0	0	0	1	1	0	1	1	1	1	0	0	1	0
47	***Poguma larvata hainana***	1	0	0	0	1	0	0	0	0	1	1	1	1	1	1	0	1	1	0
48	***Felis bengalensis hainana***	0	0	0	0	1	0	0	0	1	1	0	1	1	1	1	0	0	1	1
49	*Neofelis nebulosa*	1	0	0	0	0	0	0	0	0	1	0	1	0	1	0	0	1	1	0
50	***Lepus hainanus***	1	0	0	1	1	0	0	0	0	1	0	1	1	1	1	0	0	0	0
51	*Hystrix brachyura*	0	0	0	0	1	0	0	0	0	1	0	1	1	1	0	0	1	0	1
52	*Atherurus macrourus*	0	0	0	0	1	0	0	0	1	1	0	1	1	1	1	0	0	1	0
53	*Rattus andamanensis*	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	*Chiropodomys gliroides*	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
55	*Mus musculus*	0	0	0	0	1	0	0	0	0	1	1	1	1	0	1	0	1	0	0
56	*Niviventer coninga*	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0
57	*Rattus rattus*	1	0	0	0	1	0	0	0	0	0	0	1	1	0	1	0	1	1	0
58	*Niviventer confucianus*	0	0	1	1	1	1	0	1	0	0	1	1	1	1	0	0	1	0	1
59	*Niviventer fulvescens*	0	0	1	0	1	0	0	0	0	1	0	1	1	0	1	0	1	1	1
60	*Rattus norvegicus*	1	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0
61	*Rattus tanezumi*	0	1	0	0	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1
62	*Rattus nitidus*	0	0	1	0	1	1	0	0	0	0	0	1	1	1	1	0	1	1	0
63	*Rattus rattoides*	1	1	0	0	1	0	0	0	1	1	1	1	1	1	1	0	1	1	0
64	***Petaurista hainana***	0	0	1	0	1	0	0	0	1	1	1	1	1	1	1	1	1	1	0
65	*Belomys pearsonii*	0	0	0	0	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
66	*Hylopetes phayrei*	0	0	0	0	1	0	0	0	0	1	0	1	0	1	1	0	1	1	0
67	*Hylopetes alboniger*	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	1	0
68	***Tamiops swinhoei hainanus***	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
69	*Ratufa bicolor*	0	0	1	0	1	0	0	0	1	1	1	1	1	1	1	1	1	0	1
70	*Callosciurus erythraeus*	0	1	0	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1	0
71	*Dremomys rufigenis*	0	0	0	0	1	0	0	0	1	1	1	1	0	1	1	0	0	1	1
72	*Sus scrofa*	0	0	0	0	1	0	1	0	1	1	1	1	1	1	1	1	1	1	1
73	***Muntiacus nigripes***	0	0	0	0	1	1	0	0	1	1	1	1	1	1	1	0	1	1	1
74	***Cervus unicolor hainana***	0	0	0	0	1	0	0	0	1	1	1	1	1	1	1	0	1	1	0
75	***Cervus eldi hainanus***	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0